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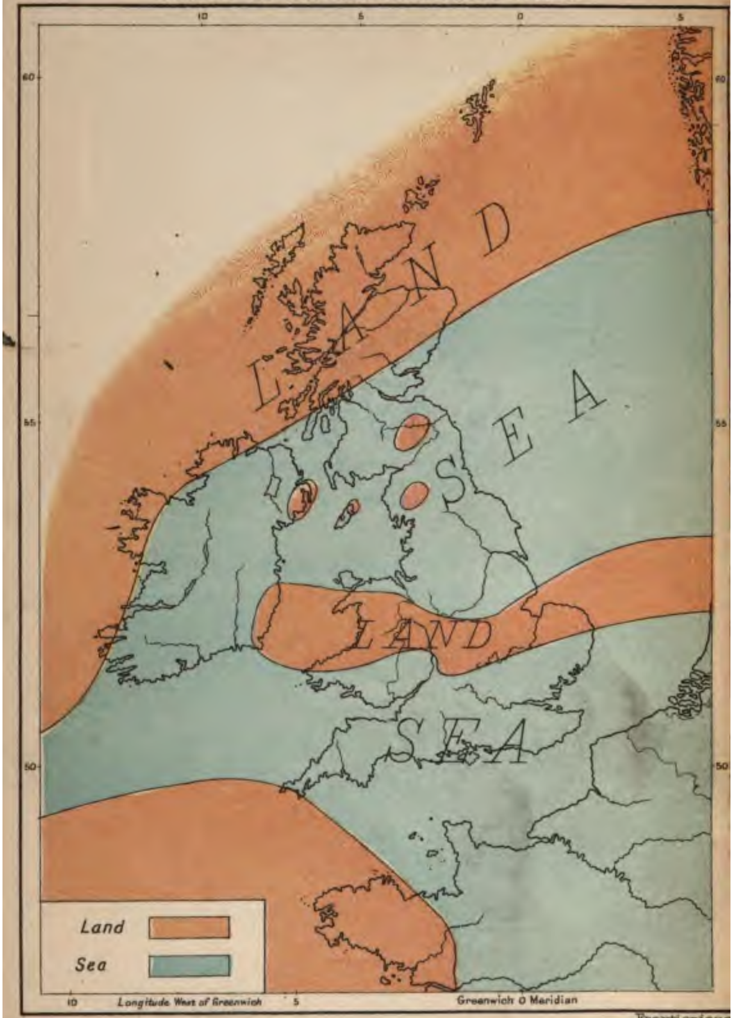
DISTRIBUTION OF LAND & WATER IN THE AREA OF THE BRITISH ISLES DURING LOWER CARBONIFEROUS TIMES.



Frontispiece

The Earth's History

AN INTRODUCTION TO MODERN GEOLOGY

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PREFACE

THE purpose of this volume is to furnish a sketch of the methods and chief results of geological enquiry, such as a reader interested in the subject for its own sake, would desire to obtain. It is not intended to be a text-book of Geology, nor is it designed with a view to the requirements of any examination. Much of the material I have used in Courses of University Extension Lectures delivered some years ago, and I have thought it useful to throw the table of contents into the form of a syllabus—somewhat condensed—such as I was accustomed to use in my lectures. In the treatment of the subject I have endeavoured to show that Geology is not a mere description of rocks and fossils, but a history, and that Great Britain (built up as it is of rocks of great diversity of age) affords a peculiarly favourable field for geological study.

The Geology of Great Britain is, indeed, in epitome the Geology of the world. Individual groups of rocks may be found developed on a grander scale in one or other of the great continental areas; particular scenic features more majestic and impressive may be found elsewhere; but in no part of the world can so great a variety of geological phenomena (no doubt often in miniature), and so complete a system of natural agencies either in active operation or displayed in their results, be observed as in Great Britain.

The purpose of the geologist is to reconstruct, from ancient fragmentary remains, the old conditions that characterised the successive stages in the evolution of the land-areas; to make out the life-history of the earth. The following are some of the problems with which he has to deal:—

What is the nature of the crust movements to which the land-areas and mountain ranges are due? What was the distribution of land and water that obtained in the area when each group of rocks was formed? What were the extent and contour of the land? What was the condition of its surface, and what the forms of life inhabiting it? What were the oceanic conditions; the depths in different parts; the forms of life inhabiting the water; and the nature and extent of the materials brought down by the rivers that poured into the seas from the land-areas of the period?

The records of this series of events are to be found in the successive groups of rocks of the Stratigraphical Series, indicated on a geological map by the different colours; and my chief object in this little volume is to present in broad outline a view of some of those results of geological research which throw light upon the structural history of the earth, and the method by which that history is worked out.

The references in the foot-notes, while they give the authority for statements in the text, are, most of them, introduced for the further purpose of guiding those readers who desire to pursue the study into greater detail, to original memoirs on the various topics treated. It is needless to observe that a real and fruitful knowledge of Geology can only be obtained by practical work in the field, and such practical work can be most profitably carried on when accompanied by the study of the best original papers dealing with the particular district or phenomena.

I cannot conclude this prefatory note without expressing my sincere thanks to my friend Professor T. McKenny Hughes of Cambridge, for permission to use Table II. and the section in Plate VIII., as well as for much valuable suggestion and help. My acknowledgments are also due to Sir A. Geikie, Professor E. Hull, and Professor A. H. Green for permission, freely granted, to base figures upon illustrations in their published papers; to Mr. Murray for permission to use illustrations from Sir Charles Lyell's *Principles* and *Student's Elements*; to Messrs. Macmillan & Co. for the like favour in the case of Figures 14, 15, 16, and 17; and to Dr. H. R. Mill for permission to include some of the maps in his companion volume on *The Realm of Nature*.

R. D. R.

CHARTERHOUSE, LONDON, E.C.

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consists almost entirely of the calcareous shells of Foraminifera, notably the genus *Globigerina*, together with shells of higher forms, such as *Pteropods*, *Heteropods*, &c., and curious bodies known as Coccoliths and Rhabdoliths, with traces also of mineral particles. 107–109

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These deposits are ancient sea-beds, or lake-beds, and the object of the Geologist is to restore the old distribution of land and water which prevailed during the formation of each.

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	S. Wales.	Mid. Eng.	Lancashire and Yorkshire.	Northumberland and Durham.	S. Scotland.
Coal Measures.	Alternations of Shales, Sandstones, Clays and Coal.				
Millstone Grit.	Thick Sandstone.	Thin or absent.	Very thick.	Occasional intercalation of thin seams of coal.	Alternations of shales, sandstones, limestones, clays and coal with iron seams.
Yoredale Rocks.	Absent.	Thin or absent.	Thick alternation of shales, sandstone and limestones.		
Carb. Limestone.	Thick and pure.	Thin and impure or absent.	Thick and pure.	Intercalations of thin coal seams.	

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[Plates I, IV, V, VI, VII, VIII, and the Frontispiece, have been prepared by Mr. J. G. Bartholomew; Plates II and III are from Mr. G. K. Gilbert's *Report on the Geology of the Henry Mountains.*]

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PART I.

‘ The earth is rude, silent and incomprehensible at first—
Be not discouraged—keep on—there are divine things well envelop’d ;
I swear to you there are divine things more beautiful than words can tell.’

WALT WHITMAN.

AN INTRODUCTION

TO

MODERN GEOLOGY.

CHAPTER I.

Progress of Geological Thought.

A century and a half ago, Geology as a science can hardly be said to have existed. Fantastic theories, the product of undisciplined imagination, were freely put forward without any pretence that they were based upon facts. Geologists busied themselves with speculations as to the origin of things instead of investigating actual existences. Natural phenomena were explained by reference to the paroxysmal action of imaginary forces of great intensity, for the old geologists were catastrophists. They saw in the contortion and dislocation of strata, in the fact that animal and plant remains were entombed in the rocks, and in the signs of former volcanic action, indications, as they believed, of the operation of forces either entirely different in kind from those now in operation, or acting with vastly greater intensity and rapidity than anything known in these later times.

To some extent doubtless their position was due to the fact that they regarded all these changes as having been brought about in a comparatively short period—a few thousand years—and they saw that if great changes had occurred in that time it was impossible to explain them without calling in the aid of unusual forces. This was the state of opinion a century ago, when Dr. James Hutton of Edinburgh, by the publication of his *Theory of the Earth*, laid a fresh and firm foundation for the science of Geology[1].

Dr. Hutton's medical training, and wide experience as a traveller and observer of nature, had prepared his mind to take broad philosophical views of the questions that came before him. As the result of his observations and researches he concluded 'that by examining things present we have data from which to reason with regard to what has been, and from what has actually been we have data for concluding with regard to that which is to happen hereafter.' No statement more infused with the true spirit of science could be conceived. He pointed out and dwelt upon the fact that constant change is a characteristic of nature. There is no quiescence. 'We are not to look,' he says, 'for nature in a quiescent state, matter itself must be in motion, and the scenes of life a continued or repeated series of agitations and events.'

He perceived that the surface of the land is everywhere undergoing destruction. He grasped the connection between this fact and the character of the earth as a habitable world, and this idea was the central point from which he started. He argued thus:—'A solid body of land could not have answered the purpose of a habitable world, for a soil is necessary for the growth of plants, and a soil is nothing but the materials collected from the destruction of the solid land. This destruction is ever in progress. The heights of our land are levelled with the shores, our fertile plains are formed from the ruins of mountains; we may therefore perceive an end to this wonderful machine.' But the thought occurs to him, is the world to be considered merely as a machine; may it not be something more?

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[1] *Theory of the Earth*, by JAMES HUTTON, M.D. (1792.)

The tissues of living creatures undergo constant decay, but there are beautiful compensatory arrangements by which renewal goes on side by side with this process. In youth renovation outstrips decay, and the creature grows as a whole; in maturity an even balance is struck; while in old age, renewal falls behind waste, eventually ceasing altogether, and death supervenes. May not the earth, like a living organism, possess powers of renewal? Faced by this question, Hutton proceeded to consider whether 'there be not a reproductive power in the earth by which a ruined constitution might be again repaired.'

Following up this fruitful and fascinating analogy, he pointed out that the materials derived from the destruction of the rocks, deposited on the sea-bottom, were in time consolidated and upheaved to form new lands. Hutton in this way laid the foundations of the science, and originated what came to be known as the Uniformitarian School in Geology, as opposed to the old Catastrophic School.

The mantle of Hutton fell upon Lyell, who in his great work on the Principles of Geology elaborated and illustrated the doctrines of the Huttonian system, that changes in the past are to be explained by reference to causes now in operation[2].

In his anxiety to avoid the pitfalls of Catastrophism, Hutton, and, in still greater degree, his followers, imposed limitations on Geology which later on had a retarding influence on the progress of the science.

The Catastrophists concerned themselves with speculations as to the origin of the earth, and explained all striking and unfamiliar phenomena by reference to the paroxysmal action of forces of unusual intensity.

The thoroughgoing Uniformitarians insisted that all the vicissitudes which had overtaken our globe had been due to the self-same causes which are now in operation, acting with unvarying intensity through all geological time. They further contended that legitimate geological enquiry should not extend backwards beyond the period of the deposition of the stratified rocks, which rocks had been deposited in water by agencies similar to those now in action. They denied that Geology had anything to do with questions as to the condition of the earth before the oldest stratified rocks were laid down.

Catastrophism and Uniformitarianism both upheld important aspects of geological truth; they were wrong in their limitations. Their place is taken by another school of geological thought—Evolutionism—which appropriates what is sound and best in each, and rejects their limitations. The modern geologist is strongly Uniformitarian in believing that the past can only be explained by studying the present: that, to use Hutton's words, 'in order to have demonstration in a case of physical enquiry, we must have recourse to the book of nature'; and Catastrophist, in holding that the natural forces may have operated with greater intensity in past times, before the deposition of the oldest fossiliferous rocks and possibly later, when the conditions were different from those that now prevail. He admits that gradual changes in the intensity and mode of action of existing forces may have been brought about during the early stages of our planet's history.

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[2] *Principles of Geology*, by Sir C. Lyell. Murray.

The modern geologist is ready to turn to the astronomer or the physicist for light on the origin of the earth, and looks forward to an indefinite extension of knowledge of the earth's history, as further advances are made in the various cognate sciences. He pushes his investigations further and further back, and seeks to know what was the condition of things before the earth possessed a solid crust differentiated into land and water. He holds as firmly as the Uniformitarian to the truth of the permanence of the laws of nature, but he contemplates natural changes in the mode of action and intensity of the forces. The central idea of his theory is continuity. The history of the earth has been continuous, as the history of a nation is continuous.

How deeply interesting it is to trace the development of a nation! What subtle influences have operated! The original racial characteristics, the physical surroundings, surface character of the country and its products, the climate, inroads of neighbouring peoples—all these and more make a set of internal and external forces under the resultant action of which the nation has moved. From age to age one generation succeeds another, and the national growth advances by stages so gentle as to be, day by day, imperceptible. Truly, a typical example of Uniformitarianism ! At the beginning of national life, movement was doubtless more erratic, and possibly more rapid; the various and diverse elements which were entering into the composition of the nation were frequently at conflict. With the growth and advance towards maturity of the national fabric, a point of greater stability was reached, when the corporate body became entitled to be called a nation. But later on, and during periods of comparative repose and slow tranquil advance, now and again some great and sudden convulsion — a revolution — breaks the even tenour of the nation's way, and makes a starting-point for new departure. The Catastrophist, who sees in a revolution only some terrible disaster falling mysteriously upon the nation without adequate traceable cause, misses the true explanation; and not less so the rigid Uniformitarian, who, while grasping the truth that the determining causes of such catastrophes are to be found in wrong conditions of national life, refuses to recognise that social forces act with more than ordinary intensity under special circumstances, and that new combinations of forces come into play which are not known during periods of national quiescence. Both are alike short-sighted, and miss the true view of the nation's life and growth. The student of history, who desires to get at the root of the matter, must not restrict his investigations to any one period in national life, or to any one set of national events. He must seek to penetrate the obscurity hanging about its origin, to discover the various racial elements which entered into its composition, to trace the effect upon it of the physical surroundings, to follow the growth of the national and social customs, and in dealing with catastrophic periods—the revolutions—must endeavour to uncover the quiet, slow-acting causes which led to them, and must understand also the upheavings of those powerful social forces which are liberated in times of convulsion and rapid change. So with Geology, the History of the Earth. The modern geologist recognises no limitations to his study. He endeavours, with all the resources furnished by the other sciences at his command, to trace the history of the earth from the beginning. He sees with the Catastrophist that there were times of rapid paroxysmal movement, and with the Uniformitarian that these catastrophes were a part of uniformity, as truly as were the alternating periods of comparative repose and readjustment of equilibrium. He believes there is nothing arbitrary in the action of the forces of nature. The harmony of orderliness and unity which characterises all nature, fills him with wonder, gives fibre to his courage, and touches him with awe; but he sees that Evolutionism does not solve the mystery of the Universe; it only pushes the mystery a little further back.

Thus the great generalisation with which the name of

Darwin will ever be associated, has influenced geological thought not less certainly than biological thought, and has led to a shifting of the point of view from which the purpose and method of the study were formerly regarded.

To the geologist of to-day, a complete and perfect Geology would mean such a full and connected history of the earth from the beginning, as would reveal the complete succession of changes in its career, and unfold the causes to which those changes were due. The purpose of geological investigation is to make contributions to this history, and its ultimate object is to furnish a complete interpretation of the earth-record. Just as the historian endeavours to reconstruct out of the written records and unwritten data within his reach an accurate and vivid picture of the condition of a nation through the successive periods of its history, so the geologist seeks to give a picture of the earth's changes from the beginning until now. A presentation of merely one aspect of national life is insufficient. The historian seeks to know the boundaries of the territory, the relation of the nation to surrounding peoples, its political constitution and code of laws, its religious observances and social customs: all that is necessary to make the old time live again. So, precisely, for the past of the earth, the geologist seeks to know for each successive period the distribution of land and water, the character of the coast-lines, the depth of water and the forms of life inhabiting it, the nature of the land and the rocks composing it, the character of the vegetation that clothed its surface, and the forms of life that inhabited its mountains, plains and valleys, the directions and character of its rivers, the sites of its volcanoes. If this succession can be completely known, we shall be able to trace the life-history of our planet through the various stages of its evolution from birth to maturity, and learn something as to its future course from maturity to decay.

For the construction of such a perfect Geology the materials are, after all, extremely meagre. The Geological Record is, at best, very imperfect; but the work of accumulating and classifying facts, which was so strenuously begun in the reaction against the baseless speculations of the old geologists, is steadily adding to the materials necessary for this purpose.

It is a really important point gained that Geology is becoming comparative. Here we detect the influence of Evolutionism. Great advances in the science of Biology became possible when the study of Anatomy passed into the comparative stage; so the dry bones of Geology began to live by the breathing of the same spirit upon them. Nothing could be more uninteresting and repellent than the treatment of the Stratigraphical Series in old text-books of Geology. No attempt was made to show by comparisons of the various sections exposed in different parts of the country that changes in lithological character and thickness of the beds, as well as in the succession of fossil forms in particular zones, might be observed, which would throw much light upon the conditions which prevailed when the beds were deposited. By these comparisons it becomes possible to learn something as to the positions of the old coast-lines, and the distribution of oceans and land areas in past times.

No doubt these restorations must be attempted with great caution, and new facts as they are from time to time revealed by fresh sections afforded by well-borings, railway-cuttings, and mining operations, may show the imperfections and inaccuracies of the generalisations. Still, if the generalisations are strictly regarded as only working hypotheses, based upon known facts, and always liable to modification in the light of fresh observations, no harm can arise, while the conscious grasp of a large generalisation vivifies the results already obtained, and is fruitful of suggestion for further investigation.

The definition of Geology as 'the history of the earth in precisely the same sense that Biology is the history of living beings,' put forward by Professor Huxley, involves a highly suggestive and perfect analogy[3]. The various departments of Geology or earth-knowledge fall naturally into subdivisions similar to those of the science of Biology. Physical Geography—the study of the earth's activities—is its Physiology; Stratigraphy, in so far as it is the study of the structure and disposition of rock masses, its Anatomy; whilst Historical Geology, or that portion of Stratigraphy dealing with the succession of Formations, is the study of the development of the earth from infancy to maturity, and is full of revelations of change and reconstruction that cannot fail to strike the mind with wonder and awe.

Geology regarded from this point of view becomes a living science. Not only is the present found to be the interpreter of the past, but the past in its turn is found to shed light upon and interpret the present.

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[3] Presidential Address, Geological Society, 1869, by T. H. Huxley. Reprinted in *Lay Sermons*. Macmillan & Co.

The importance of Physical Geography as the prelude to Geology is pointed out in every text-book, but it is important also to note that Geology is essential for the right understanding of Geography, because the present condition of the earth is the latest term in a long series, and is the direct result of all that has gone before, whether our knowledge enables us to trace all the previous conditions and changes or not. The realisation of this fact gives a fresh stimulus to the study of Geography, which, regarded in its larger aspect as the 'study of man's physical environment on the surface of the planet, and of the interaction between it and the human race,' forms a most fascinating and practically useful branch of knowledge.

It is unnecessary to point out that the special value and importance of the study of science, as a mental discipline, lies in the method of investigation employed. The careful observation and recording of facts; the drawing of general conclusions from those facts, and the testing of generalisations by reference to fresh facts—these are the steps of that inductive method by which the advances of science have been accomplished. It was not, as we have seen, until this method began to be fearlessly and consistently applied to geological investigation that Geology made any solid or rapid advance.

CHAPTER II.

THE BEGINNINGS OF THE EARTH-HISTORY.

It is an old device of writers of fiction to depict a character of calm, placid, and unruffled exterior presenting few outward signs of past inward turmoil and strife, and then gradually, by subtle indications, to prepare the mind of the reader for the discovery of an active or tragic history concealed beneath that apparent outward calmness. The geologist in dealing with the earth's history finds himself much in the position of such a reader. The surface of the land appears from day to day so permanent and unchanging as to seem the very type of that which is stable and lasting. The eternal hills look down on the changing fortunes of man from generation to generation. Yet by careful study of the records preserved in the rocks, the geologist finds disclosed an earth-history that includes marvellous successions of events, and displays many vicissitudes of fortune.

The materials available for working out national history are furnished by (1) written documents handed down from the past, and (2) unwritten records—the products of the life and activity of the nation—from which may be inferred something as to its characteristics. It is clear that the further back we go in the history of a nation the more are we dependent upon indirect sources of knowledge and the less upon documentary evidence, until at last a point is reached beyond which writing does not go and history becomes 'prehistoric.' This 'prehistoric' history of the earth is the domain of the science of Geology. The present fades imperceptibly into the past. The historian carries back the story to the point at which writing begins, the archæologist takes us back one step further, as far as traces of human workmanship are found, and it then falls to the geologist to open up the history of those long ages which preceded the appearance of man upon the earth. He finds that the same principles govern the changes of the present and the past, and a study of the earth as it is with its activities forms the basis of the study of the earth as it has been, so that Physical Geography in its larger sense makes a foundation for Geology. The present physical changes of the earth are indeed but Geology in the making, just as the national events and changes that we call Politics, are but History in the making. Thus Geology may be regarded as the sum of an indefinite number of past Physical Geographies.

If we now study the distribution of land and water on the earth's surface, we shall find that a comparison of the outlines and contours of the continental areas brings out some interesting coincidences and contrasts. It will be seen from the map (Plate I) that the distribution of land and water is by no means regular and uniform. Of the 197 millions of square miles that constitute the earth's surface, 53 millons only are land and 144 million water. Furthermore, it will be seen that there is a greate accumulation of land in the Northern Hemisphere tha in the Southern, and the extent to which the land massed together may be gathered from the well-know fact that if, instead of dividing the Globe into tw hemispheres by the equator it is divided into tw hemispheres in such a way that the greatest possib amount of land may be in one hemisphere, we find th Great Britian is at the pole of that Land Hemisphere— in the very centre of the land. It is certainly a curiou if not a significant circumstance that this small countr of ours, the home of a people whose genius for comme cial enterprise has carried its influence to the ends of th earth, should be situated in the centre of the lan hemisphere—the very heart, as it were, of the habitab world.

The study of the map of the World will further sho that the great continents fall into three pairs arranged right angles to the equator, the two Americas, Europe an Africa, Asia and Australia. The eye cannot fail to struck by the tendency to a triangular form with the ap to the South, which is particularly marked in North an South America, and in Africa. There is, in addition, comparative absence of indentation of coast-line in th continents of the Southern Hemisphere, South Americ Africa and Australia ; while the presence in the northe continents of numerous peninsulas pointing to the South, and of enclosed seas, such as the Gulf of Mexico, Mediterranean, and the Malayan Sea, all constitute striking features by way of contrast. It will be seen

s of continental land is deter-
f mountains running through its
g as it were its backbone. Thus
d the Andes determine the north
Americas, while the Himalayas
y the Caucasus and the Alps,
ture of that great Europasian
over thousands of miles East to
then forces itself upon us, how
of land and water been brought
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that the lie of each mass of continental land is determined by a lofty range of mountains running through its whole length and forming as it were its backbone. Thus the Rocky Mountains and the Andes determine the north and south trend of the Americas, while the Himalayas continued westwards by the Caucasus and the Alps, make the central feature of that great Europasian continent that stretches over thousands of miles East to West. The question then forces itself upon us, how has this distribution of land and water been brought about, and how are the curious coincidences and contrasts in the contours and vertical outlines of the continents to be explained? Has the land always presented the same configuration of promontory and inlet, cape and bay, the same outline against the clear sky, of hill and dale, mountain and valley, which it presents to us to-day? Is the land, as it seems to be, the type of that which is firm, stable, and lasting? How are such questions to be answered? The life of man is short, and little can be observed in the threescore years and ten of a human life. Unless we are able to submit the earth to careful scientific observation for periods measured by thousands of years, how can we learn what changes are taking place upon its surface affecting its larger features? The answers to such questions as these must be sought for in the application of the scientific method. What is invisible to the outward eye becomes revealed to the trained imagination by a process of reasoning from observed facts, and we may pass by successive steps of incontrovertible argument to new and far-reaching conclusions.

There is a body of evidence clear and unmistakable proving that the outlines and contours of the land are ever slowly changing; that there is a steady decay of rock-masses; that the land areas and their physical features, as we know them, are the result of gradual evolution, the steps of which may be traced and the proximate causes indicated. Large problems remain unsolved and many difficulties seem insurmountable, for after all the science is still in its infancy; but the advances already made have cleared the way and have made it possible to go some distance towards constructing an adequate geological history of the earth.

Let us now consider what knowledge can be gained as to the earliest history of the earth. For the first beginnings we must turn to the science of Astronomy. We learn from the astronomer that the earth is a spheroidal mass rotating on its axis, one of the group of heavenly bodies revolving around the sun. Evidence furnished by recent spectroscopical investigation is confirmatory of the substantial truth of the Nebular Hypothesis, for it shows that the chief chemical elements composing the earth are present in the sun. According to that hypothesis the solar system is the result of the condensation of a nebulous mass which broke up into a central incandescent sun and the surrounding planets.

We may best gain an idea of the probable course of events in this primitive condition of our planet, by conjecturing what would be likely to happen if the solid earth, sea, and air were subjected to the influence of heat sufficiently intense to cause them to re-act upon one another. Chemical research has shown that, while moderate heat favours chemical combination, an intense degree of heat produces decomposition. In the nebulous mass, therefore, the elements would be uncombined. As it cooled a temperature would in time be reached at which chemical combination became possible; the oxygen would combine with silicon to form silicic acid, which would unite with the various bases to form the silicates of which the molten globe must have consisted. Surrounding this primitive globe we should expect that there would be an atmosphere containing immense quantities of aqueous vapour, and charged with acid gases formed by the union of sulphur, carbon, chlorine, and nitrogen, with oxygen. As cooling proceeded, a condensation of these acid gases and aqueous vapour would take place, flooding the original surface of the earth with a highly heated acid solution which would re-act upon the silicates. Gradually the acids by combination with bases would be largely removed from the waters, and the atmosphere would also in a similar way be slowly purified of the acid vapours it originally contained. The incoming of animals and plants when the earth had cooled sufficiently to permit of the existence of life, introduced new factors, re-acting in important ways upon the ingredients of the atmosphere, the ocean, and the solid crust, and giving rise to decompositions and new combinations.

Apart from this theory however there is abundant evidence that the earth was at one time in a molten condition. Its shape—a spheroid flattened at the poles—is that which a rotating molten body would assume; the rise in temperature in descending into deep mines, and the existence of volcanoes with the extrusion of molten lava during eruptions all point to this conclusion.

What, then, would happen if such a rotating molten mass were slowly cooling? The view which has been popularly held is as follows. The surface gradually cooling down to the point at which solidification began, a solid crust would necessarily be eventually formed, which would thicken as the cooling continued. The lowering of temperature would be accompanied by the contraction of the mass, and the outer crust, in accommodating itself to the lessening dimensions of the interior portion shrinking by loss of heat, would tend to be thrown into wrinkles and folds along certain lines, just as the skin of a dried apple wrinkles when the interior portions shrink by loss of moisture. Although there can be no doubt that movements of the crust of such a molten mass would result in this way from secular cooling, physical and chemical considerations render it certain that they would be by no means as simple as might at first sight be supposed.

We turn now to examine whether the earth presents features analogous to those which a cooling rotating mass might be expected to present.

A glance at a map of the World shows that the earth's crust consists of alternating elevated portions that form the continental masses, and depressed portions in which the oceans lie. Each great continent is distinguished, as was previously pointed out, by a massive mountain system, forming, as it were, its backbone, and these mountain chains are found to consist of highly crumpled and contorted rocks. This so far accords with the theory of contraction due to secular cooling. We pass on to consider what is known as to the depth and contours of the ocean beds.

The recent deep sea explorations (Plate I) have revealed the fact that the great oceans, the Atlantic, the Pacific, and the Indian, are depressions in the crust of very considerable depth. The deepest sounding taken during the Challenger explorations was 27,450 feet (about five miles) in the Pacific off the Ladrone Islands. Now it is a curious fact that the highest peak of the Himalayas rises to something over this height, so that the surface of the ocean forms a plane about midway between the highest point of the land and the lowest depth of the sea. We have no right, however, to conclude from that fact, that the *average* height of the land and the *average* depth of the ocean are the same. Deep sea soundings have in point of fact shown that the average depth of the ocean is about 15,000 feet (roughly speaking three miles) while the average height of the land is, according to Murray, about 2,100 feet (two-fifths of a mile). It appears also that the sea bottom is somewhat flat and less diversified in outline than the land surface, while the slopes that run parallel to the continental coast-lines are often abrupt and steep, so that a very great depth is frequently reached only a short distance from shore. These facts have obviously important bearings on the question of the permanence and antiquity of the great oceanic and continental areas.

The larger and more striking physical features of the earth's crust, seem therefore to be such as might well have been blocked out by great earth movements along a few well defined lines. If this be so, and the thickening crust was thrown into a few great folds in remote times, the elevated portions of which formed the first land, and the depressed portions formed the ocean basins, we may proceed to ask whether the mountain ranges, such as the Rocky Mountains, the Andes and the Himalayas, that form the backbones of the great continents, are portions of the original land. To this question we can give an unhesitating answer in the negative. As the original surface crust was solidified from a molten condition, it must presumably have been composed of rocks presenting strong resemblances to the solidified lavas which are the products of modern volcanic eruptions. This, however, is not as a rule the character of the rocks that now constitute land areas. Broadly speaking the rocks found composing the crust of the earth may be divided into two great groups; those which have consolidated from a molten condition, the *Igneous* rocks, and those which have been deposited as sediments in water, the *Aqueous* or *Sedimentary* rocks. Under the head of Aqueous rocks are included Limestones, which are accumulations of the shells and other hard parts of aquatic organisms. Intermediate between these groups is a third, known as the *Metamorphic* rocks which are either igneous or aqueous rocks, that have since their original formation undergone changes, owing to subjection to pressure, strain, heat, or chemical action, which have induced much alteration in their structure and have modified their original character. (See Table III.)

Of the two chief groups of rocks, the Aqueous and the Igneous, the former is the more important to the geologist, as it includes the bulk of the rocks constituting the land. The great mountain masses of the world are as a rule composed of Aqueous and Metamorphic rocks, enormously folded and contorted. If Igneous rocks occur they belong to the Plutonic group which are known to have consolidated at a depth below the surface and under great pressure. They now only appear at the surface, as the result of the removal by denudation of the strata that originally covered them.

It is clear, therefore, that the continental areas are, as they now stand, not composed of the original surface rock of the crust, but have been built up of rocks formed since the destruction of the first solid crust that covered the surface of the molten globe. The results of geological investigation seem to point beyond question to great earth movements bringing about the elevation of extensive areas of the crust and resulting in the making of continents, and to lesser movements giving rise to mountain ranges. The larger deformations of the crust may be compared to the broad ocean swells that roll in upon the shore, and the mountain-making movements to the surface waves that ruffle the crests of these great rollers.

It becomes necessary, as the next stage in our investigation, to consider the nature and extent of the processes of destruction to which the land surface is, and has been, subject.

PART II.

DESTRUCTION OF LAND

(DENUDATION).

'Consider how this habitable earth, with all its rock-built mountains and flowery plains, is for ever growing and perishing in eternal birth and death—consider how the winds and lightnings, and storms of rain and hail, and flooded rivers and lashing seas are for ever cutting, mining, gnawing away, confringing, colliding and comminuting the hills and the shores, yea, and the sites of high-domed cities,—until every mountain shall be brought low and every capital city shall lie deep "at the bottom of the monstrous world," where Helice and Buris, Sodom and Gomorrah lie now:—this, I suppose, you call destruction:—but consider farther how the nether fires are daily and nightly forging, in the great central furnaces, new granite mountains, even out of that old worn rubbish; and new plains are spreading themselves forth in the deep sea, bearing harvests now only of tangled algæ, but destined to wave with yellow corn. Now, in all this wondrous procedure, can you dare to pronounce that the winds and the lightnings, which tear down, degrade, destroy, execute a more ignoble office than the volcanoes and subterranean deeps that upheave, renew, re-create? Are the nether fires holier than the upper fires? The waters that are above the firmament, do they hold of Ahriman, and the waters below the firmament of Ormuzd? Do you take up a reproach against the lightnings for that they only shatter and shiver but never construct? Or have you a quarrel with the winds because they fight against the churches and build them not? In all nature, spiritual and physical, do you not see that some powers and agents have it for their function to abolish, and demolish and derange—other some to construct and set in order? But is not the destruction, then, as natural, as needful, as the construction? Rather tell me, I pray you, which is construction—which destruction? This destruction *is* creation: death is birth, and

"The quick spring like weeds out of the dead."'

JOHN MITCHELL, *Jail Journal.*

CHAPTER III.

THE AGENTS OF DESTRUCTION.

THE most cursory study of the surface of the land reveals an unceasing destruction of the rocks which compose it. The evidences of ruin are abundant, and may be observed wherever a surface of rock is exposed to the action of the weather. This subject has been dealt with so fully by writers on Geology, and in particular in such a masterly way by Sir Charles Lyell, in his classical work *The Principles of Geology* that it is unnecessary here to do more than suggest two or three instances as types and samples of destructive operations.

A visit to any rocky coast-line brings home vividly to the mind the potency of the sea as a destructive agent. If the observer wishes to study the operation in an impressive form, he may betake himself to the north coast of Scotland. At Duncansby Head, or across the Pentland Firth on the western coast of the Orkney Islands, during a storm, he will see the sea at its grandest, and will realise what a powerful natural battering-ram it forms, under the potent and persistent action of which the cliffs are surely, although slowly, being eaten away. Such a monument of destruction as the Old Man of

Hoy, on the west coast of the Orkney Islands (Fig. 1) is peculiarly striking. It is a column of sandstone rock over 600 feet high, standing in front of the sea cliff, with which it is connected by a low ridge. The correspondence between the bedding of the column of rock, and the bedding or the cliff of the mainland, shows unmistakably, that the two were once continuous, the intervening portions of rock having been removed by the action of the great billows that come rolling in upon the shore. All

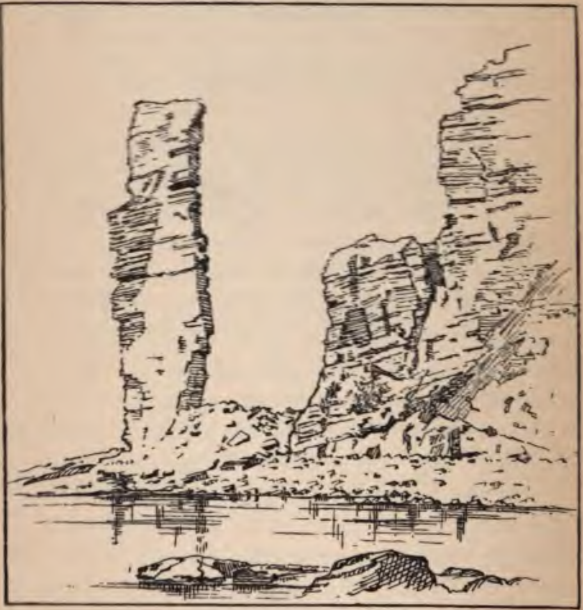

Fig. 1.—THE OLD MAN OF HOY.

along the beach lie strewn fragments of rocks, the results of destructive operations in the past. These during storms are hurled against the cliff by the waves, and in their turn play an important part in carrying on the demolition of the land. 'The scene,' says Sir A. Geikie, 'tells its own tale of ceaseless waste, and needs no lecture or text-book for its comprehension. Pinnacles and turrets of richly tinted yellow and red sandstone roughen the upper edge of the cliff, often fretted into the strangest shapes, and worn into such perilous narrowness of base, that they seem doomed to go headlong down into the gulf below when the next tempest sweeps across from the West. Buttresses, sorely rifted and honeycombed, lean against the main cliff as if to prop it up, but separated from it by the yawning fissures, which will surely widen until they wedge off the projecting masses, and strip huge slices from the face of the cliff. One sees, as it were, every step in the progress of degradation. It is by this prolonged splitting and slicing and fretting, that the precipice has been made to recede, and has acquired its shattered, but picturesque contours. The Old Man is thus a monument of the retreat and destruction of the cliffs of which it once formed a part. To what accidental circumstance it may have owed its isolation cannot be affirmed with certainty. But it shares in the prevalent decay. Every year must insensibly tell upon its features. On the calmest day some motion of air always plays about the giddy crest of these precipices, and a surge, with creaming lines of white foam, sweeps round its base. But when a westerly gale sets in, the scene is said to be wholly indescribable. The cliffs are then enveloped in driving spray torn from the solid sheets of water which rush up the walls of the rocks for a hundred feet or more, and roll back in thousands of tumultuous waterfalls[1].'

No careful observations and estimates have been made on any large scale of the rate of destruction of the land under the action of the waves of the sea. On some parts of our own coast, where the rock consists of soft clay or other easily-destroyed material, the sea eats away several feet in a century; but where the rock is hard and tough the rate of destruction is extremely slow. Sir A. Geikie has roughly estimated that the sea eats away, on an average, at the rate of ten feet in a century, which he admits, however, to be a mere supposition, and probably a higher rate of erosion than can fairly be claimed for marine action[2].

Evidences of ruin not less obvious than these seen on a sea beach are afforded by the condition of mountain regions. 'It is,' as an Alpine climber once humorously remarked, 'melancholy to observe the bad state of repair of mountain tops.' At the foot of every steep rocky slope, accumulations of angular fragments of rock, forming banks of screes, may be seen, which are in the main the result of the action of frost. The sketch (Fig. 2) gives a good example of this. The property possessed by water of expanding when in the act of freezing, renders it a natural wedge of singular potency.

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[1] *Geological Sketches at Home and Abroad*, by Sir A. GEIKIE, p. 35. Macmillan & Co.

[2] Trans. Geol. Soc. of Glasgow. Vol. III: *On Modern Denudation*, by Sir A. GEIKIE.

When rain water soaks into the joints and fissures of the rocks, and the temperature falls below freezing point, expansion takes place as the water solidifies, forcing the portions of the rock apart. The results of this destructive action of frost are more apparent in those regions and countries where the range of temperature on either side of the freezing point is more extreme than in our own country. In Arctic regions, when the short summer sets in, and the icy grip of winter upon the rocks begins to relax, the whole surface of the country presents an aspect of ruin, which is very impressive.

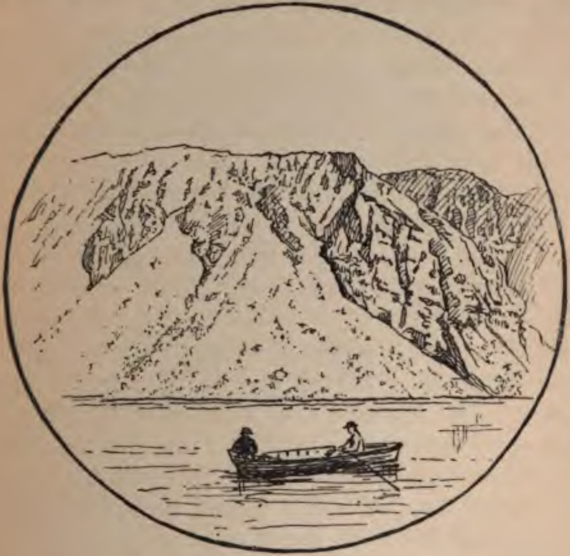

Fig. 2.—SCREES. WASTWATER.

In regions above the line of perpetual snow another agent of destruction makes its appearance, in the form of glaciers. By the slow, yet unceasing, movement of the glacier forcing the fragments of rock frozen into its base over the rocky bed of its valley, a smoothing and grinding down of the surface takes place just as if the rocks had been subjected to the action of a file. At the same time the glacier acts as a transporting agent by conveying upon its surface, in the form of moraines, the screes and débris that tumble upon it from the rocky slopes of the valley down which the ice moves. The stream flowing from underneath the glacier, thick with fine mud scraped from the rocks by the great ice file, and the mounds of moraine débris at the end of the glacier, alike testify to the vast unceasing decay and destruction of rock which is taking place in snow-clad regions.

As illustrating the action of another great natural agent the Falls of Niagara may be taken. The river, to which this impressive natural feature is due, flows in the upper part of its course over an elevated tableland to the falls, where a magnificent volume of water pours over the cliff 165 feet and then rushes with great velocity down the narrow gorge which extends for seven miles, and terminates suddenly at the escarpment at Queenstown. A study of the sections exposed on each side of this gorge, shows clearly that it has been carved out by the action of the river. The processes of excavation may be easily studied at the falls. The geological structure of the cliff is simple: the upper part consists of a bed of limestone ninety feet thick; the lower part, of a bed of soft shale (Fig. 3). By the impingement of the water at the foot of the falls, clouds of spray are thrown up which eat away the soft shale, and by the additional aid of frost during winter, the undermining process proceeds until fragments of the overlying limestone break off. Thus the falls are steadily receding. Sir Charles Lyell, during a visit to the spot, came to the conclusion that the average recession was about one foot

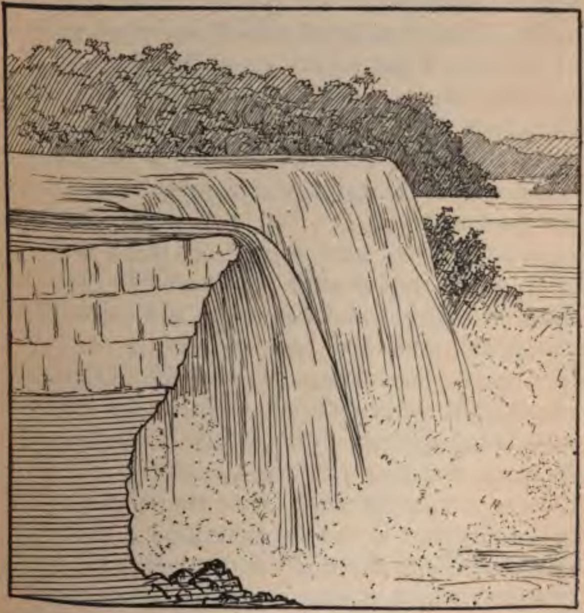

Fig. 3.—DIAGRAMMATIC SECTION OF THE FALLS OF NIAGARA.
Illustrating the mode of recession of the Falls.

a year; that would imply that 35,000 years had been required for the excavation of the gorge and the retreat of the falls from the escarpment at Queenstown to their present position. Other estimates give a lower figure as the rate of retreat of the falls, and there can be no doubt that it is variable.

The detailed study of almost any river valley will afford proof, if not as striking as that just adduced, at any rate quite as conclusive, that rivers operate destructively upon the rocks over which they pass, and that these destructive operations have resulted in the removal of masses of material that once occupied the valleys in which the rivers now run.

It may be well here to point out that a river acting alone, if that were possible, would tend to cut a steep-sided channel just like that made by a lapidary's saw. The gravel, sand, and boulders washed down by the river, are the instruments by which the cutting down is effected, just as the diamond powder is the real cutting agent of the lapidary. This *cutting* and *deepening* action of rivers may instructively be contrasted with the destructive *weathering* action of the atmospheric agencies. It is convenient to use the more general terms *erosion* or *denudation* to describe the destruction and removal of rocks without specific reference to the particular operations by which it was brought about. In nature a single agent is rarely if ever found operating absolutely alone; concurrently with the cutting by the river, a weathering of the sides of the gorge goes on under the influence of alternations of heat and cold, of wind, *rain* and frost. The particular form of the valleys will depend upon two main factors, (1) the nature and arrangement of the rocks, (2) the relative activity of the deepening action of the river, and the weathering action of the atmospheric agents. Where the sub-aerial action is dominant, the valleys will be wide and shallow with gentle slopes; on the other hand, where the river is the chief agent, and rain and frost have little effect, the valleys will be narrow and steep-sided.

So marked and unmistakable are the signs of erosion in many districts, that it may be said with truth that the rivers existed before the mountains that now surround them. If we imagine the valleys filled up, the mountains as we know them would cease to be. In place of the diversity of outline of mountain and valley would appear the gentle undulations of a high plateau.

There is no part of the world where the condition of things just referred to is more magnificently illustrated than in the wonderful Cañon region of the western territories of North America. In the superb volumes of the United States Geological Survey detailed descriptions of the unique scenery of that district are given, together with a wealth of beautiful illustration never surpassed in geological literature.

In the Grand Cañon district, which covers an area of between 13,000 and 16,000 square miles in north-western Arizona and Utah, wonderful series of valleys occur which display to perfection the action of rivers as cutting agents. Owing to the extreme aridity of the region, there is a scantiness of soil and an absence of vegetation which render it easy to read the geological history with a completeness that would be otherwise impossible. The valleys of our own country, and those in all temperate regions where the rainfall is abundant, are the combined result of the deepening action of the rivers and the widening action of the atmospheric agents. In the Grand Cañon district, with its exceptionally arid climate, the weathering action of rain and frost is at a minimum, while the action of rivers produces its maximum effect. The result is a magnificent series of remarkable valleys designated Cañons.

The general structure of such a country, as consisting of a plateau, out of which the river-valleys have been carved, is well brought out in Fig. 4. The same characteristic features are also illustrated in Plate III, which represents another part of the Grand Cañon area, to be further described in a later chapter. Although the powerful effect of rain is nearly absent, yet owing to the scantiness of vegetation and consequent exposure of the surface-rock to alternations of heat and cold, and the action of wind, the cañon walls undergo a considerable amount of destruction. These weathering agents are Nature's finer tools by which the more delicate natural sculpture is effected, and certain remarkable scenic features result.

The escarpments in which the nearly horizontal beds terminate, and the sides of the cañons, are sculptured and fretted by these atmospheric agents into surfaces of marvellous beauty. The varying degrees of resistability of the successive beds, give rise to gables, pinnacles, and columns that impart a peculiar architectural character to he features of these valleys. Moreover the beds differ, t only in structure, but also in colour, and the superb

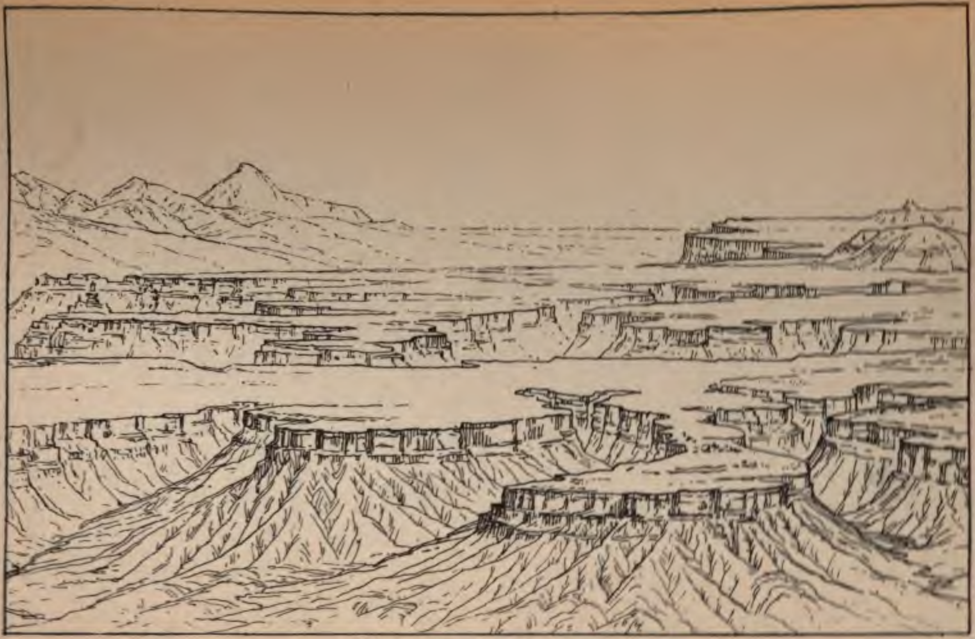

Fig. 4.—THE MESA VERDE.

Part of Cretaceous plateau carved into Cañons (U. S. Geol. Survey, *Tertiary History of the Grand Cañon District*, Dutton).

PLATE II

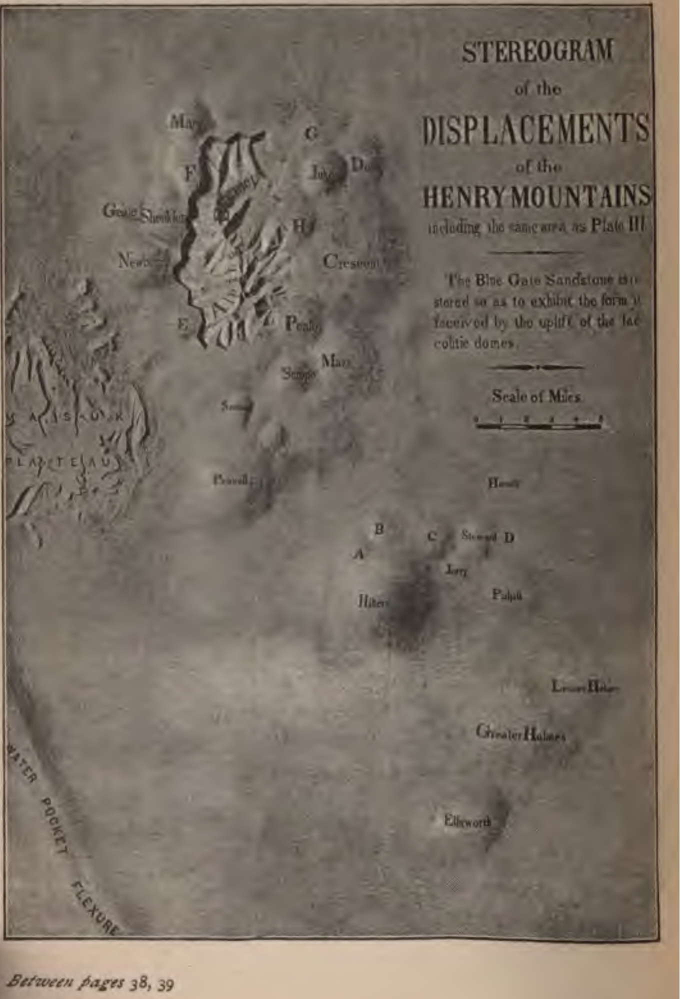

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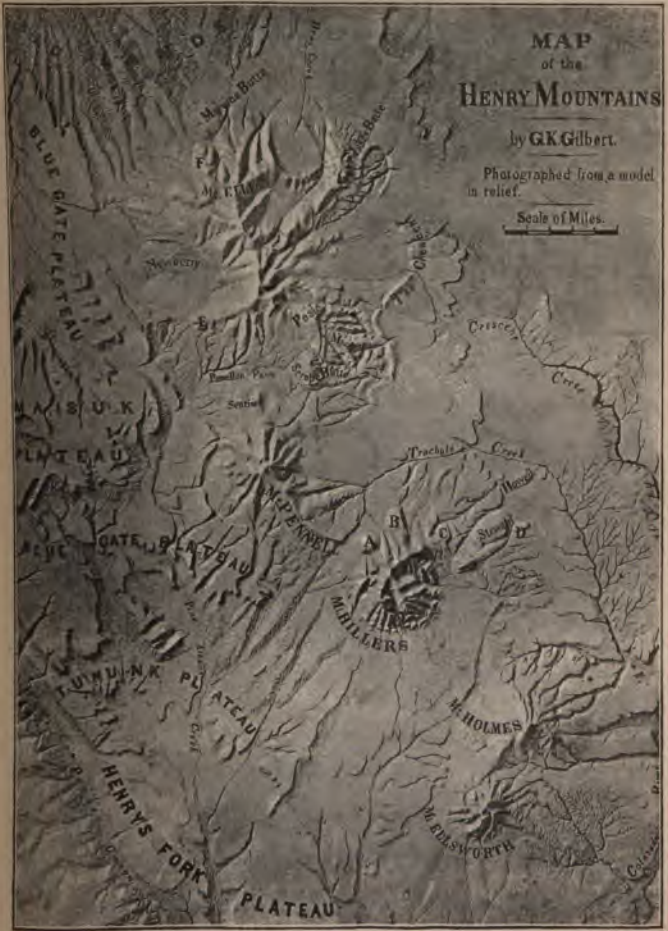
PLATE III


MAP
of the
HENRY MOUNTAINS
by G.K.Gilbert.
Photographed from a model in relief.
Scale of Miles.
BLUE GATE PLATEAU
MAISUK PLATEAU
BLUE GATE PLATEAU
TUMUINK PLATEAU
HENRYS FORK PLATEAU
Mt. ELLEN
Mt. PENNELL
Mt. HILLERS
Mt. HOLMES
Mt. ELLSWORTH
F
E
A
B
C
D
Trachyte Creek
Crescent Creek
Pennellen Pass
Sentinel
Colorado

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'In coming time,' says Captain Dutton, 'it will, I believe, take rank with a very small number of spectacles, each of which will, in its own way, be regarded as the most exquisite of its kind the world discloses.' He describes how the surface at their feet dropped down by a cliff and talus 1200 ft. upon a broad and rugged plain cut by narrow cañons. The surface of the ground with its scanty soil displayed the most wonderful colours, chocolate, maroon, purple, lavender, magenta, with broad bands of toned white laid in horizontal belts, strongly contrasting with each other, and owing to the varying slope of the surface, winding about like the contours of a map. Their eyes, however, were quickly taken from the superficial features, and were arrested by a wonderful object standing on the other side of the cañon, rising 4000 ft. above the river, and making the central and commanding figure of the picture. This magnificent object, called by Captain Dutton the Western Temple (Fig. 5), consisted of a complex group of white towers, springing from a central pile, and mounting upwards to the clouds.

We must let Captain Dutton describe it in his own words: 'Out of their midst,' he says, 'and high over all, rises a dome-like mass which dominates the entire landscape. It is almost pure white, with brilliant streaks of carmine descending its vertical walls. At the summit it is truncated, and a flat tablet is laid upon the top, showing its edge of deep red. It is impossible to liken this object to any familiar shape, for it resembles none. Yet its shape is far from being indefinite; on the contrary, it has a definiteness and individuality which extort an exclamation of surprise when first beheld. There is no

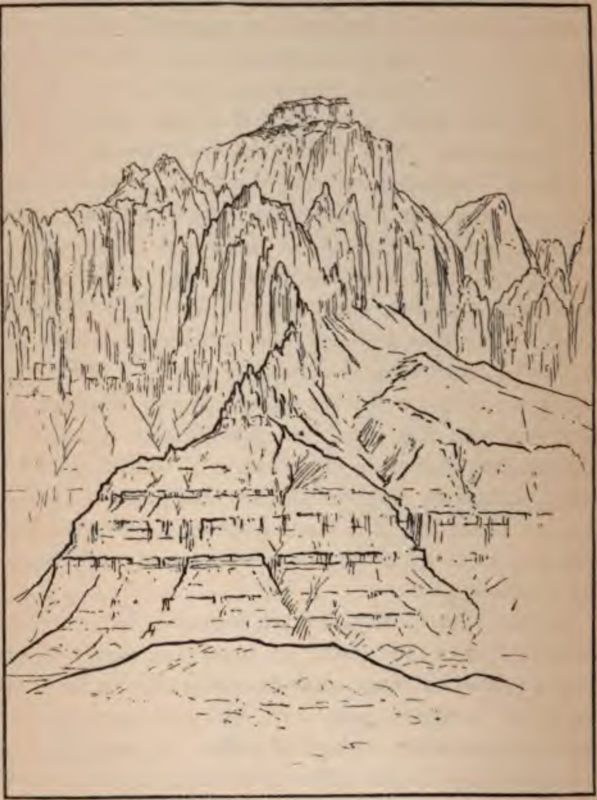

Fig. 5.—THE WESTERN TEMPLE OF THE VIRGEN VALLEY.
(U. S. Geol. Survey, Dutton.)

name provided for such an object, nor is it worth while to invent one. Call it a dome; not because it has the ordinary shape of such a structure, but because it performs the function of a dome. The towers which surround it are of inferior mass and altitude, but each of them is a study of fine form and architectural effect. They are white, and change to a strong, rich, red below. Dome and towers are planted upon a structure no less admirable. Its plan is indefinite, but its profiles are perfectly systematic. A curtain wall of 1400 ft. high descends vertically from the eaves of the temple, and is succeeded by a steep slope of ever-winding base courses leading down to the esplanade below. The curtain-wall is decorated with a lavish display of vertical mouldings, and the ridges, eaves, and mitred angles are fretted with serrated cusps. Across Little Zion valley, a twin temple occurs, its upper mass is a repetition of the one which crowns the western pile. It has the same elliptical contour, and a similar red tablet above. In its effect upon the imagination it is much the same. Nothing can exceed the wondrous beauty of Little Zion valley, which separates the two temples and their respective groups of towers. Nor are these the only sublime structures which look down into its depths, for similar ones are seen on either hand along its receding vista until a turn in the course carries the valley out of sight. In its proportions it is about equal to Yosemite, but in the nobility and beauties of the sculptures there is no comparison. It is Hyperion to a satyr. No wonder the fierce Mormon zealot, who named it, was reminded of the Great Zion, on which his fervid thoughts were bent—"of houses not built with hands, eternal in the heavens!"'

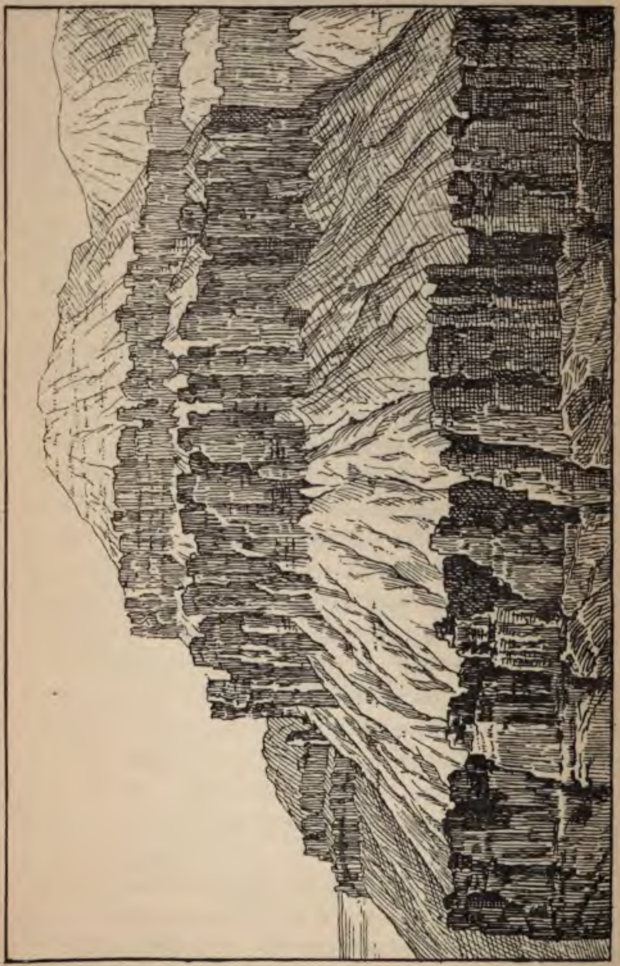

Fig. 6.—A GABLE WITH PINNACLES IN THE TOROWEAP VALLEY.

These results of the destructive operations of nature, marvellous as they are, are even surpassed by the phenomena of the Grand Cañon in the southern part of the area. Captain Dutton, in giving an account of his course down the Toroweap valley which opens into the Grand Cañon, describes the sides of the walls of the cañons as assuming profiles of wonderful grace and nobility. 'Far in the distance,' he says, 'they betoken a majesty and grandeur quite unlike anything hitherto seen. With vast proportions are combined simplicity, symmetry, and grace, and an architectural effect as precise and definite as any to be found in the terraces.'

Some idea of the beauty and complexity of the gables and pinnacles of this valley may be gathered from the sketch in Fig. 6. At the lower end of the Toroweap, where it opens into the Grand Cañon, the scenery assumes colossal proportions. The Cañon consists of a broad upper chasm, from five to six miles in width, with walls 2,000 feet high. Between these is a rough rocky plain which, in the overpowering presence of such walls, seems relatively smooth and uniform. In this plain is cut the inner chasm 3,000 feet deep, and from

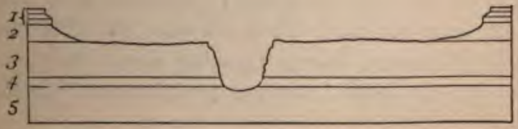

Fig. 7.—SECTION OF THE GRAND CAÑON AT THE FOOT OF THE TOROWEAP VALLEY.

1 2, 3, and 4, Carboniferous; 5, Silurian. (U. S. Geol. Survey, Dutton.)

3,500 to 4,000 feet wide (Fig. 7). 'The magnitude of the chasm, however,' says Captain Dutton, 'is by no means the most impressive element of its character; nor is the inner gorge the most impressive of its constituent parts. The thoughtful mind is far more deeply moved by the splendour and grace of nature's architecture. Forms so new to the culture of civilised races, and so strongly contrasted with those which have been the ideals of thirty generations of white men, cannot indeed be appreciated after the study of a single hour or day. The first conception of them may not be a pleasing one. They may seem merely abnormal, curious, and even grotesque. But he who fancies that nature has exhausted her wealth of beauty in other lands strangely under-estimates her versatility and power. In this far-off desert are forms which surprise us by their unaccustomed character. We find at first no place for them in the range of our conventional notions. But as they become familiar we find them appealing to the æsthetic sense as powerfully as any scenery that ever invited the pencil of Claude or of Turner.'

The profiles of the gables and pinnacles into which the walls are cut, are described as graceful and systematic in the highest degree. It is hard to realise, says the narrator, that this is the work of blind nature. We feel like mere insects crawling along the street of a city flanked with immense temples, and finding it deserted.

These remarkable results of the destructive operations of nature are sufficiently obvious and impressive to produce a marked effect on even the least contemplative mind, and it will now be interesting to follow out another line of argument leading to the same conclusion, but affording at the same time the means of making a numerical estimate of the rate and extent of denudation.

CHAPTER IV.

ESTIMATES OF THE EXTENT OF THE DESTRUCTIVE OPERATIONS.

WHILE detailed measurements have been made in a few instances with the view of estimating the rate of decay of the land, there has been no systematic attempt to carry out on a sufficiently extensive scale such a series of observations as would make it possible to compare the rates of decay in different rocks, under varying conditions of position and climate, with any approach to accuracy. It is possible, however, even without complete measurements, to gain clear and vivid impressions of the stupendous scale on which the destruction of land is taking place at the present time.

Sir Archibald Geikie gave, some years ago, an account of his own observations on the decay of tombstones with the view of measuring the rate of rock-weathering[1]. He pointed out that actual time measures have been so few in geological enquiry that any attempt might be welcomed which promised to supply one. His investigations were chiefly made in the older burial-grounds of

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[1] *Geological Sketches at Home and Abroad* (ch. viii. 'Rock-weathering measured by the Decay of Tombstones'), by Sir A. GEIKIE. Macmillan & Co.

Edinburgh. It must not be forgotten, however, that the rate of weathering in the neighbourhood of a town, where the air contains traces of sulphuric and other acids resulting from the combustion of coal, doubtless greatly exceeds that of rocks under ordinary conditions in districts remote from centres of industry. He found that around Edinburgh the materials used for tombstones were of three kinds :—(1) calcareous rocks—marbles and limestones ; (2) sandstones and flagstones ; (3) granites. In the case of the first, the decay was so rapid that in a very few years the inscriptions became utterly illegible. One tablet erected in 1785 was so far decayed as to require restoration in 1803. Eighty years later the decay had proceeded to such an extent that the marble had been dissolved away from the centre of the slab to a depth of about a quarter of an inch.

Observation showed, however, that the rate depended to some extent upon the degree of exposure of the marble ; the amount of waste being far less apparent in stones screened from the action of rain. On the whole Sir A. Geikie concluded that inscriptions on slabs of marble 'exposed to the weather in such a climate and atmosphere as that of Edinburgh are utterly destroyed in less than a century.'

In the case, however, of the second group of rocks—sandstones and flagstones—the results were widely different. The siliceous sand of which the rocks consisted, associated with little or no iron or lime, resisted the action of weather remarkably well. A tombstone erected in 1646 still showed the original chisel marks on the polished surface with perfect distinctness. Two hundred years had effected hardly any change upon the surface of the stone.

The third rock—granite—has been used for so short a time as a monumental stone that no definite estimate of the rate of decay could be made.

It is clear that no general conclusion as to the rate of destruction of the land surface can be drawn with even approximate accuracy by observations upon the weathering of particular surfaces of rock, seeing that so much depends upon the position of the exposed surface and the composition and structure of the particular slab of rock observed.

There is, however, another line of investigation which leads to more interesting and suggestive results.

If we consider what becomes of the material resulting from the decay of rock we see that it must either be added to the surface soil or be washed by rain into streams and rivers, and so be conveyed to the sea.

There can obviously be no constant and large addition to the surface soil since its accumulation tends to protect the rock which it covers from the further action of rain and frost, and a continuance of the destructive process therefore implies and necessitates a constant removal of so much of the surface soil as is necessary to enable the destructive operations to proceed. It is evident that if we can ascertain what amount of material is carried by rivers from the land annually, we have a measure of the extent of the destructive operations taking place.

Water as a transporting agent acts in a double capacity. It conveys material in invisible chemical solution and in visible mechanical suspension. In studying the destruction of a given area of land, therefore, what we desire to ascertain is the amount of solid material which is transferred from above to below sea-level, both in solution and suspension, by the agency of the rivers traversing that area.

Let us deal first with the solids held in solution. Seeing that rain is the source of all terrestrial waters, and that the rivers are altogether fed from the clouds, it is easy to make an approximate estimate of the work done by a river in transporting material in solution.

Analysis of rain water shows that it contains but a very small quantity of solid matter. What occurs is chiefly common salt derived from spray of the sea. Rain water collected at spots remote from the sea and large towns, evaporated to dryness, leaves no solid residue. River or spring water, on the other hand, evaporated to dryness in the same way, leaves a considerable residue, consisting as a rule of a variety of salts, of which carbonates, sulphates and chlorides of calcium, magnesium and the alkalies, together with silica and oxide of iron, are the most important.

The amount of material held in solution in this way varies considerably in different springs and rivers. The water of the Rabate fountain, Balmoral, contains as little as ·98 grains per imperial gallon, but this is exceptionally low. The amount in the waters of St. Anne's Well, Malvern, is 3·97 grains per gallon. In contrast with this may be taken the old sulphur well at Harrogate, the highly charged waters of which contain over 1000 grains per gallon. The monthly average for 1872 was 1046·56 grains, about 2¼ oz.

Similarly, the amount occurring in the waters of different rivers varies considerably. An analysis of the waters of the Dee above Balmoral, on March 9, 1872, gave only 1·06 grains per gallon. One of the feeders of Thirlmere, in Cumberland, and the waters of the lake itself, contain only 1·92 grains per gallon. On the other hand, the upper waters of the Thames contain over 20 grains per gallon, and some of its tributaries a still larger amount. The lower waters of rivers flowing through great industrial centres, and consequently polluted by sewage, show a much higher proportion of solid material, which rises to over 100 grains in some cases, which is largely however made up of organic impurities[2].

The solvent action of pure water upon the minerals composing the bulk of the rocks of the crust is extremely small, but rain water in its passage through the air dissolves a certain amount of carbonic and other acid gases which greatly increase its solvent power. Limestone (calcium carbonate), which is almost insoluble in pure water, is dissolved by water holding carbonic acid in solution. The removal of the carbonic acid gas causes a deposition of calcium carbonate as a white precipitate. Hence the efficacy of boiling as a means of softening water in limestone districts. The carbonic acid is driven away by the heat, and the carbonate consequently deposited. This gas is one of the products of the decomposition of animal and vegetable matter, and is taken up by the rain water in its percolation through the surface soil where such decomposition is always taking place. Rain water does not, however, depend for its solvent power solely upon the carbonic acid gas dissolved out of the atmosphere. Out of the soil the rain takes up also certain organic acids—the humus acids—which like carbonic acid are products of the life and decay of animals and plants. It seems certain from recent investigations that these humus acids are of far greater importance as agents of destruction than was formerly supposed.

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[2] Rivers Pollution Commission (1868), *Sixth Report.*

Under the term humus is included that complex mixture of organic substances which occurs in nature under many forms. It occurs in living vegetation, in the excrescences attending unhealthy growths, in mould, dead leaves, decaying seaweed, as well as in the rotting leaves and weeds of the deeper layers of the soil, and in the dung of animals and birds.

In a paper on the geological action of the humus acids, Mr. Alexis Julien[3] has pointed out how the development of these potent acids seems to have relation to the presence of insect remains, through whose intervention, apparently, nitrogen, which is one of the essential constituents of these acids, is supplied for their formation. Mr. Darwin[4] many years ago showed that worms play a most important part in the formation of the vegetable mould which covers the surface of the land, by adding to the organic material of the soil the leaves which they draw into their burrows, and which on decaying give rise to various organic acids. Mr. Darwin found also that the contents of the intestines of the worms as well as their castings were so acid that it seems probable that the process of digestion induces chemical changes that lead to the formation of certain of these humus acids in the decayed leaves which the worms swallow. He showed also that the acids in the intestines of worms have the power of deoxidising and dissolving peroxide of iron to a far larger extent than acetic acid or even diluted hydrochloric, sulphuric, and nitric acids, and he observed that they acted energetically on limestone (calcium carbonate) and upon silica which occurs so largely in the crust of the earth in the form of quartz, flint and sandstone.

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[3] Proceedings of the American Association for the Advancement of Science, Saratoga, 1879. Paper by ALEXIS JULIEN on *Humus Acids*, vol. xxviii, p. 301.

[4] *Earth Worms*, by CHARLES DARWIN, p. 236. Murray.

Seeing that the vegetable mould has passed many times through the bodies of worms, it seems likely, therefore, that these creatures contribute largely to the generation of the humus acids.

Mr. Julien refers to investigations upon the action of organic acids, such as citric acid, upon various minerals, which afforded conclusive proof that they are capable of producing very considerable decomposition. Analyses of water from bogs, soils, and decaying moss demonstrated the presence of a large proportion of soluble silica which was clearly attributable to the action of these humus acids. For example, the waters of the marshes and subsoil of the Landes near Bordeaux, where the district is underlaid by a layer of siliceous sand, have been found peculiarly rich in silica, and the analysis of the waters of other river basins abounding in humus, such as those of the St. Lawrence and Mississippi, show in like manner the presence of large quantities of dissolved silica.

Living vegetation, such as mosses and lichens, by virtue of the organic acids which they contain, have been observed greatly to corrode the rocks on which they grow. In fact the humus acids seem to be endowed with a special activity in that direction even where the surface soil is thinnest.

Extreme instability is a marked characteristic of these organic acids, and as they are readily broken up by oxidation, they speedily disappear during the process of solution carried on by them, so that their presence cannot be detected in river water which conveys the products of their action to the sea.

Thus, as Mr. Julien points out, a zone of gentle but ceaseless chemical action envelopes, and has enveloped the earth from the earliest times of which we have record. It is represented by the layer of surface soil which serves as the laboratory for the production of a series of acids of great corrosive power which have been constantly transferred over the surface by streams, and into the rocks by percolating rain water.

Below lies the crust of the earth composed of crystalline mineral substances, above is the atmosphere, a storehouse of gaseous and liquid agents capable of entering under certain conditions into combinations powerful to decompose the mineral constituents of the crust. Intervening between these two comes the layer of surface soil—humus—which is the medium of continual reaction and change. Rain water charged with these potent acids, obtained during its passage through the surface soil, and the action of which no kind of rock seems able entirely to resist, sinks into the pores and fissures of the underlying rock. The calcareous rocks, as we have seen, are readily soluble, and even the igneous rocks yield, although more slowly, to the disintegration which follows upon the decomposition of certain of their component minerals, notably the felspars.

We conclude, therefore, that the solid substances held in solution in springs and rivers have been dissolved out of the rocks by water in its passage through them. In order to estimate the amount of material removed from the drainage area of any river, and consequently to estimate the rate of destruction of the land within that area due to the solvent action of atmospheric waters, it is only necessary to ascertain the number of gallons of water carried to the sea annually by the river, and the number of grains of solid material held in solution per gallon after deducting the amount due to organic impurities. The credit of first applying this method is due to Mr. Mellard Reade, who brought the subject under the notice of the Liverpool Geological Society in a presidential address on 'Chemical Denudation [5].'

In the Reports of the Royal Commissions on Water Supply and the Pollution of Rivers, the necessary data may be obtained for making these calculations in the case of several British rivers. The Thames in particular, owing to the fact that it is the main source of the water supply of the metropolis, has been studied with great care and completeness.

The average amount of solid materials in Thames water for 1868 [6], according to Professor Frankland's analysis, was 20·11 grains per imperial gallon. Analyses for other years gave slightly varying results, and Professor Prestwich, in his presidential address to the Geological Society in 1872, took as a fair average from year to year 20·68 grains.

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[5] *Chemical Denudation*, by T. MELLARD READE, being the Presidential Address to the Liverpool Geological Society, 1876–7.

[6] Royal Commission on Water Supply (1868), *Appendix*, p. 94.

A certain small proportion of this material consists of organic impurity, and a deduction of 1·68 grains on this account reduces the total to 19 grains per gallon of solid material dissolved out of the rocks by the action of rain water. Of this, about two-thirds is calcium carbonate, dissolved limestone, while the remaining third is made up of sulphates of calcium, potassium, and sodium, together with chlorides of sodium and potassium, carbonate of magnesium, with traces of silica, iron, and other substances. It is only necessary, therefore, to know the annual discharge of water by the Thames in order to make it possible to estimate the destructive work which is performed by the solvent action of water in the drainage area of the river.

TABLE showing approximately the average rainfall in the Thames basin, the discharge by the Thames at Kingston, and the evaporation yearly between April 1855 and April 1865.

Rainfall.		*Discharge at Kingston.*		*Evaporation.*	
Inches.	*Millions of gallons.*	*Inches.*	*Millions of gallons.*	*Inches.*	*Millions of gallons.*
26·87	1,434,506	9·07	484,550	17·83	951,713

The area of the Thames basin above Kingston is 3,676 square miles, and one inch of rain over the Thames basin gives 53,375,000 gallons of water.

The foregoing table, based upon figures furnished to the Royal Commissioners by Mr. J. T. Harrison[7], gives the results of ten years' observations from 1855 to 1865.

It will be seen that the 484,550 million gallons of water that passed Kingston annually, each containing 19 grains, carried to the sea 587,145 tons of solid material dissolved out of the rocks. All this, it will be noted, is carried in invisible solution, and quite apart from the sandy and muddy material held in mechanical suspension and transported seawards chiefly during floods. The drainage area of the Thames above Kingston is 3676 square miles, and therefore the 587,145 tons removed from this area per annum is equivalent to 159 tons from every square mile[8].

To obtain a perfectly accurate estimate for the whole of Great Britain of the amount removed in this way as the result of the destructive action of aqueous agents, it would be necessary to make similar calculations in the case of each particular river, so as to obtain its average annual discharge of water, and the average amount of solid materials dissolved in its waters. This laborious process has not been carried out as yet, but a very simple method may be applied which will enable us to arrive at an approximate result for the whole country. This will be dealt with in the next chapter.

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[7] Royal Commission on Water Supply (1868), *Minutes of Evidence*, pp. 181–83.

[8] Prof. Prestwich, taking a somewhat lower estimate of the annual discharge, made it 149 tons per square mile. *Q. J. G. S.* vol. xxviii, p. lxvii.

CHAPTER V.

ESTIMATES OF THE EXTENT OF THE DESTRUCTIVE OPERATIONS (*continued*).

THE first question we have to consider is whether the destructive work done by the Thames in this way represents a fair average of what is done by the other rivers of Great Britain. It has already been pointed out that the water of rivers is derived from rain, but a study and comparison with one another of the figures showing rainfall and discharge given in the previous chapter reveals a peculiar state of things, for it proves that the whole rainfall does not find its way into the river channels. The rainfall is 26·87 inches, but only 9·07 inches is discharged by the river. What then becomes of the balance? Evidently it must be evaporated back into the atmosphere or taken up by vegetable and animal life, and we may approximately ascertain what amount is disposed of in that way by deducting from the total rain-fall in a particular district the total discharge by streams and rivers from the same district.

Turning again to the table, it will be noticed that while the average yearly rainfall in the Thames Basin was 1,434,506 million gallons, the annual discharge at Kingston was 484,550 million gallons, leaving a balance of 951,713 million gallons, which was disposed of mainly by evaporation. So that, broadly speaking, we may say that only one-third of the annual rainfall of the basin flows to the sea in the Thames.

One consideration, however, must here not be lost sight of, depending upon the geological structure of the Thames basin. About one-third of the area consists of impermeable clays and two-thirds of permeable beds, such a chalk, oolitic limestones, sandstones &c. Over the surface of the impermeable clays the rain, as it falls, speedily runs in channels and thence into the Thames, without percolating into the rock below the surface soil. But, over the permeable area, there will be a large and constant percolation of the water through the mass of the underlying rock, resulting in the storage of the water as in a sponge. This water eventually makes its way to the surface again at lower levels in springs, and it is in the main this water which in its percolation through the permeable beds dissolves the materials carried in solution to the sea.

Another effect of this subterranean storage of water is to regulate the water supply in a way highly advantageous for human purposes.

In an area of impermeable rocks heavy and continued rain immediately gives rise to floods, while a period of drought quickly cuts off the water supply. Whereas in districts of permeable rock the percolation of water during a period of heavy rain diminishes the tendency to floods, while the supply is kept up in times of drought for lengthened periods from the subterranean stores.

It follows that in years of small rainfall there will be a draw upon the subterranean reservoirs which will result in a larger discharge by the river than the average proportion of the rainfall, while in years of heavy rainfall the subterranean accumulation of water will be made up and the discharge by the rivers will be smaller than the average proportion.

It will be noted, further, that in an area of permeable rocks, small rainfall, and gentle undulating surface, the conditions are favourable for a maximum loss by evaporation, since all the conditions favour the slow transference of the water to the river channel whence it is conveyed seawards, and these are also the conditions favourable to destructive solvent action. Whereas impermeability of rock associated with great irregularity of surface, such as distinguishes a mountain area, together with heavy rainfall, furnish conditions unfavourable for a maximum loss by evaporation in consequence of the rapid transference of the water seawards, and unfavourable to extensive solvent action. It is obvious that in these two extreme conditions we see the double action, chemical and mechanical, of running water well displayed. The former, i.e. permeability and regularity of surface, is highly favourable to large chemical action and small mechanical action, the latter, i.e. impermeability and irregularity of surface, to large mechanical action and small chemical action.

We may take as examples of these two conditions manifested in their extreme forms, the Thames basin and Wales. The rocks of Wales belong to the older geological formations, and exhibit as a rule far less permeability and solubility than the newer beds amongst which the Thames and its tributaries take their rise. The calcareous beds of the oolites and the chalk are largely affected by the solvent action of rain water holding carbonic acid in solution. On the other hand, the hard, resisting, sandy, and slaty rocks of Wales yield little to that action, and the river water of that district contains a far smaller proportion of solid material than the waters of the Thames.

It is clear that the amount of solid material held in solution in the waters of a river will largely depend upon the character of the rocks composing the surface, and it is obvious also that the absolute quantity of solid material transported to the sea depends upon *two* factors, the solubility of the rocks through which the rain water percolates, to which reference has just been made, and the total quantity of water discharged daily by the rivers. The latter is dependent upon the rainfall, and an examination of the conditions in the various areas reveals a very curious, rough, self-regulating, compensatory adjustment of these two factors.

The amount of rainfall is largely determined by the elevation of the land, and these old rocks of the West, tough and resisting in character, usually present rugged mountainous scenic features. The average rainfall over these areas amounts to from 50 to 75 inches per annum, while in some parts it rises as high as 130 or 140 inches. On the other hand, the eastern part of England, a gently undulating country of no great elevation, bounded on the south by the Thames and on the west by a line drawn from Oxford to Sunderland, has a rainfall of under 25 inches, while the large tract of mid-England

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from that line to the borders of Wales, shows a slightly higher average, which does not, however, exceed 30 inches or thereabouts.

The dependence of rainfall upon elevation is clearly brought out by a comparison of the two maps (Plates IV and V), and the detailed figures fully bear this out. The following table gives two illustrations of this principle.

	Cumberland Lake District.		*Welsh District.*	
	Whitehaven.	*Loweswater.*	*Portmadoc.*	*Festiniog.*
Elevation above Sea.	90 feet.	336 ft.	20 ft.	600 ft.
Rainfall	43·53 in.	67·29 in.	45·75 in.	74·80 in.

These facts show that mountainous regions act as condensers of atmospheric moisture. The currents of moist air impinging upon the mountain slopes are caused to ascend into higher and colder regions, and, as the pressure of the atmosphere diminishes with every foot of rise above sea-level, the ascending current of air is ever passing from a region of higher into one of lower pressure, and consequently expands. This expansion is attended by a lowering of temperature, with the result that condensation of moisture takes place for the reason that there is a limit to the quantity of aqueous vapour which a fixed volume of air can hold at any given temperature. When, therefore, the air is cooled below its saturation point condensation of vapour takes place in the form of mist or rain.

There is in addition another circumstance which favours condensation. The capacity of the atmosphere to hold aqueous vapour increases with the temperature, but the increase is in a higher ratio than the rise of temperature. It follows that if two volumes of air, both saturated with aqueous vapour, one at a high and the other at a low temperature, be mixed together, the two volumes at the intermediate temperature will not be able to hold as much vapour as the two separately, and consequently a portion will be deposited as mist or rain. For these various reasons the rainfall of the high land of the West and North is very much heavier than that of the East and South. Are we therefore justified in assuming that in those districts the total amount of material per square mile removed by the solvent action of the atmospheric waters is largely in excess of that carried by the Thames? This question can only be satisfactorily answered by careful study of the actual figures in each case. The materials for this study may to a large extent be obtained from the Sixth Report of the Rivers Pollution Commission already referred to, which gives detailed analyses of numbers of British river waters, from which the following conclusions may be drawn.

The average amount of solid material dissolved in the waters flowing over the igneous, metamorphic, Archæan, Cambrian, and Silurian rocks of the West and North is, according to the figures given in the Report (pp. 35, 36), 3·59 grains per imperial gallon. The average for Wales (to confine our attention for a moment to one special district) is 3·19 grains per gallon. The rainfall over more than half the Principality is between 50 and 75 inches per annum; around the coast it sinks to between 30 and 40 inches, while over the high mountain regions of Carnarvonshire and Merionethshire it rises to upwards of 80 inches.

It will probably not be very wide of the mark if we take 65 or 66 inches per annum as the average for the whole of Wales. We have seen that the amount of rainfall dispersed by evaporation in the Thames basin is about 17 inches per annum, leaving about 9 inches as the amount run off the surface into the Thames.

It seems certain that the amount lost by evaporation in Wales, where the flow of water is more rapid and the conditions less favourable, will be less, perhaps considerably less, than 17 inches. In order, however, to keep well within the mark let us take the figure as 17 inches. Deducting this from 66 inches we have left 49 inches run off the surface into the rivers, i.e. nearly six times as much as runs into the Thames. If we consider an area in Wales of 3,676 square miles equal to the area of the basin of the Thames above Kingston, the amount of water which flows from this area daily to the sea is six times as great as that which flows in the Thames. While, however, each one of the gallons of Thames water carries 19 grains of solid material to the sea, each gallon of water in Wales carries only 3·19 grains, that is, one-sixth of the amount. The total result is approximately an equal amount removed from each area, which in the Thames we have seen to be equivalent to 159 tons for every square mile. Thus it appears that although the amount per gallon carried by different British rivers varies greatly, yet, owing to variations in rainfall and in the conditions of permeability of rocks, it seems not improbable that on the average the proportion removed from every square mile over the whole country is approximately the same.

Mr. Mellard Reade, in his address on Chemical Denudation, previously referred to, working out the calculations in more detail for different districts, arrives at an average of 143 tons per square mile. Let us then take this lower figure in order not to over-estimate the amount.

The area of Great Britain is 90,000 square miles, 143 tons removed from every square mile make a total of over twelve and a half million tons of material carried down in invisible chemical solution to the sea every year by British rivers.

This work of transportation of the products of chemical denudation seawards, which is going on in this way in the rivers of Great Britain, is similarly going on in all the rivers of the world.

On the continent of Europe the Rhine is estimated to carry in solution 11·9 grains of solid material per gallon, which gives a total of 5,816,805 tons per annum. The Rhone is estimated to carry in solution 10·92 grains per gallon, which gives 8,290,464 tons per annum. An analysis of the water of the Danube at Vienna gives 8·69 grains per gallon in solution, which amounts to 22,521,434 tons per annum. Add to these all the other European rivers, draining together an area of three and three-quarter million square miles.

Then pass to Asia. The Brahmapootra drains an area three times as great as the whole of Great Britain, and presumably does a work proportionately large; the

Ganges an area four times as great; the Yellow River an area six times as great. To these again add all the other rivers of the vast Asiatic continent draining an area of over sixteen and a quarter million square miles.

Turning to America, the St. Lawrence is estimated to carry 11·23 grains per gallon in solution, and drains an area more than three times as great as the whole of Great Britain. The waters of the Mississippi carry 15·48 grains in solution per gallon, and it drains an area more than twelve times as great as Great Britain. The Amazon, from an analysis of its waters, appears to carry 4·14 grains per gallon in solution, and drains an area of 3,000,000 square miles, more than thirty times as great as the area of Great Britain. Add to these again all the other great rivers of North and South America, and to these the rivers of Africa and Australia. Now, bringing the mind back to our own country, and realising that British rivers carry no less than twelve and a half million tons of solids in solution to the sea every year, some conception may be obtained of the enormous destruction which is taking place. Indeed, the mind stands paralysed in the attempt to realise the magnitude of the work done by all the rivers of the world in this silent and unceasing way, for there is here revealed to us a stupendous process of destruction and transportation ever in operation, unseen, impalpable, beyond the direct ken of our senses, and of which we could have known nothing except by the application of the scientific method.

This destruction, immense as it is, represents only a portion of the destructive action of running water, and that the portion to which least attention has hitherto been paid.

Rivers are in addition carrying in mechanical suspension vast quantities of solid material seawards. Let us endeavour briefly to gain some idea of the extent of this operation. Rivers considered from the point of view of the transportation of material in mechanical suspension may be divided into two groups, (1) those flowing from ice-covered regions — the waters of which are *always* charged with fine sediment ground down by the action of the Glaciers; (2) ordinary rivers—the waters of which are only *intermittently* charged with sediment.

With regard to the first group—Glacier rivers—the following interesting account by Mr. Ruskin of an attempt made by himself to estimate the extent of their destructive work may be quoted :—

'Close beside the path by which travellers ascend the Montanvert from the valley of Chamouni, on the right hand, where it first begins to rise among the pines, there descends a small stream from the foot of the granite peak known to the guides as the Aiguille Charmoz. It is concealed from the traveller by a thicket of alder, and its murmur is hardly heard, for it is one of the weakest streams of the valley. But it is a constant stream, fed by a permanent, though small, glacier; and continuing to flow even to the close of the summer, when more copious torrents, depending only on the melting of the lower snows, have left their beds—"stony channels in the sun." The long drought which took place in the autumn of 1854, sealing every source of water except these perpetual ones, left the torrent of which I am speaking, and such others, in a state peculiarly favourable to *observance* of their *least* action on the mountains from which they descend. They were entirely limited to their own ice fountains, and the quantity of powdered rock which they brought down was, of course, at its minimum, being nearly unmingled with any earth derived from the dissolution of softer soil, or vegetable mould, by rains. At three in the afternoon on a warm day in September, when the torrent had reached its maximum strength for the day, I filled an ordinary Bordeaux wine flask with the water where it was least turbid. From this quart of water I obtained twenty-four grains of sand and sediment more or less fine. I cannot estimate the quantity of water in the stream; but the runlet of it at which I filled the flask was giving about two hundred bottles a minute, or rather more, carrying down therefore about three-quarters of a pound of powdered granite every minute. This would be forty-five pounds an hour; but allowing for the inferior power of the stream in the cooler periods of the day, and taking into consideration, on the other side, its increased power in rain, we may, I think, estimate its average hour's work at twenty-eight or thirty pounds, or a hundredweight every four hours. By this insignificant runlet, therefore, rather more than two tons of the substance of the Mont Blanc are displaced and carried down a certain distance every week; and as it is only for three or four months that the flow of the stream is checked by frost, we may certainly allow eighty tons for the mass which it annually moves. It is not worth while to enter into any calculation of the relation borne by this runlet to the great torrents which descend from the chain of Mont Blanc into the valley of Chamouni. I but take this quantity, eighty tons, as the result of the labour of a scarcely noticeable runlet at the side of one of them, utterly irrespective of all sudden falls of stones and masses of mountain (a single thunderbolt will sometimes leave a scar on the flank of a soft rock looking like a trench for a railroad), and we shall then begin to apprehend something of the operation of the great laws of change which are the conditions of all material existence, however apparently enduring.'

In the case of the second group—ordinary rivers—it is mainly during floods that material is carried in mechanical suspension. At such times the water is thick with sediment, the amount of which, however, varies constantly according to the degree of flood. In order to make any accurate estimate of the amount carried to the sea annually, in this way, a most elaborate series of daily, if not hourly, observations would need to be taken. Nothing of this kind has yet been done for British rivers.

In the case of the Mississippi, however, some very complete and carefully conducted investigations on the amount of material carried in mechanical suspension by the river were made by Messrs. Humphreys and Abbot[1]. They found that the average amount of sediment held in suspension in the waters of the Mississippi is $\frac{1}{1500}$ part of the weight of water, i.e. about $1\frac{1}{2}$ lb. in every ton of water. The mean annual discharge of water by the Mississippi is given as 19,500,000,000,000 cubic feet, which at 36 feet to the ton is 541,666,666,666 tons. The total amount of material held in mechanical suspension discharged annually is therefore $\frac{1}{1500}$ of that amount, i. e. 362,723,214 tons, to which must be added 20,833,333 tons, the amount which it is estimated the river pushes along the bottom to the sea, in addition to that held in mechanical suspension, making a total of over 383,000,000 tons. As the drainage area of the Mississippi is 1,244,000 square miles, we see that the amount of material removed by the river in mechanical suspension is about 300 tons from every square mile. This is equivalent to $\frac{1}{4566}$ of a foot off the whole surface per annum, or one foot in 4566 years; but as the specific gravity of the sediment is about 1·9, while that of the rock is 2·5, the amount removed is equal to one foot of rock in about 6000 years[2].

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[1] *Report on the Physics and Hydraulics of the Mississippi.* HUMPHREYS and ABBOTT (1861).

Let us now compare this with the amount carried by the river in chemical solution. According to an analysis given by Mr. Mellard Reade[3], the total of solids in solution in the waters of the Mississippi is 15·48 grains per gallon. Knowing the annual discharge of the river, we find that in round numbers 150,000,000 tons of material are carried in chemical solution every year into the Gulf of Mexico by the Mississippi. The drainage area of the Mississippi is 1,244,000 square miles, therefore the amount removed from every square mile of surface is 120 tons per annum.

We have already seen that the corresponding amount which the Thames and its tributaries take their rise. The calcareous beds of the oolites and the chalk are largely affected by the solvent action of rain water holding carbonic acid in solution. On the other hand, the hard, resisting, sandy, and slaty rocks of Wales yield little to that action, and the river water of that district contains a far smaller proportion of solid material than the waters of the Thames.

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[2] *Climate and Time*, by JAMES CROLL. Ch. xx. Daldy, Isbister & Co.

[3] *The Denudation of the Two Americas*, by T. MELLARD READE, being the Presidential Address to the Liverpool Geological Society, 1884-5, pp. 9 and 10.

It is clear that the amount of solid material held in solution in the waters of a river will largely depend upon the character of the rocks composing the surface, and it is obvious also that the absolute quantity of solid material transported to the sea depends upon *two* factors, the solubility of the rocks through which the rain water percolates, to which reference has just been made, and the total quantity of water discharged daily by the rivers. The latter is dependent upon the rainfall, and an examination of the conditions in the various areas reveals a very curious, rough, self-regulating, compensatory adjustment of these two factors.

The amount of rainfall is largely determined by the elevation of the land, and these old rocks of the West, tough and resisting in character, usually present rugged mountainous scenic features. The average rainfall over these areas amounts to from 50 to 75 inches per annum, while in some parts it rises as high as 130 or 140 inches. On the other hand, the eastern part of England, a gently undulating country of no great elevation, bounded on the south by the Thames and on the west by a line drawn from Oxford to Sunderland, has a rainfall of under 25 inches, while the large tract of mid-England

PART III.

CONSTRUCTION OF LAND

a. DEPOSITION

b. MOVEMENTS OF THE CRUST

c. ADDITIONS BY EXTRUSION FROM THE INTERIOR.

'The ruins of the old land furnish the materials of the new.'

JAMES HUTTON.

CHAPTER VI.

SHALLOW-WATER DEPOSITS.

IT will now be clear that the destructive operations under which the land is slowly but surely worn down fall broadly into three classes: (1) the chemical action of surface water; (2) the mechanical action of surface water; and (3) the action, mainly mechanical, of the sea round coast-lines.

The first is an operation which goes on over the whole surface of the land, varying in extent, no doubt, according to the composition of the surface rocks, but everywhere unceasing, for the mantle of soil affords no protection to the underlying rock,—indeed, it increases the solvent power of the water percolating through it by furnishing the supply of humus acids and carbonic acid that result from the decay of organic matter, and to which the destructive action of water is so largely due. The second—the mechanical action of water—is exerted along certain lines where the water runs in channels, and is a potent force in the moulding of the surface of the land into its characteristic features. The third agent—the sea—gnaws away around the coast-lines, eating its way slowly into the heart of the land-areas.

The first operation tends to produce very gently undulating surface features. The second results in bold irregularities of surface, while the third gives rise to level plains of marine denudation. Under the unceasing action of these agencies, the land year by year perishes, and, as we have seen, at the present rate of destruction the whole of the continental land would be reduced to sea-level within a measurable period.

The consideration of the extent of this destruction leads to the question whether there is any antagonistic process in nature making for the construction of land. This was the problem which Dr. James Hutton set himself to solve in his *Theory of the Earth.* 'The heights of our land,' he said, 'are thus levelled with the shores, our fertile plains are formed from the ruins of the mountains, and these travelling materials are still pursued by the moving water and propelled along the surface of the earth. If the vegetable soil is thus constantly removed from the surface of the land, and if its place is thus to be supplied from the dissolution of the solid earth as here represented, we may perceive an end to this beautiful machine.' 'But,' he adds, 'is this world to be considered thus merely as a machine, to last no longer than its parts retain their present position, their proper forms and qualities?' This question he answered unhesitatingly in the negative, and proceeded to point out an alternative, viz. that it 'might be also considered as an organised body, such as has a constitution in which the necessary decay is naturally repaired in the exertion of those productive powers by which it had been formed.'

In the deposition of materials on the sea-bed and in the movement of elevation to which the crust in one part or another is ever subject, we have, as Dr. Hutton pointed out, 'the reproductive operation by which the ruined constitution is again repaired.'

It is necessary now to trace the course of these 'ruins of the old land' to their final destination, and it will be convenient to consider, in the first place, the material conveyed in mechanical suspension.

It is clear that any check to the rapid flow of water carrying suspended matter will lead to a deposition of some of the coarser material. During floods, when a river on reaching the plains overflows its banks, a very considerable deposition of sediment may take place, forming the alluvial flats which characterise the lower reaches of many river courses.

One of the best instances of these alluvial deposits is furnished by the case of the Nile. 'Egypt,' says Sir Samuel Baker, 'has been an extraordinary instance of the actual formation of a country by alluvial deposit; it has been *created* by a single river. The great Sahara, that frightful desert of interminable scorching sand, stretching from the Red Sea to the Atlantic, is cleft by one solitary thread of water. Ages before man could have existed in that inhospitable land, that thread of water was at its silent work: through countless years it flooded and fell, depositing a rich legacy of soil upon the barren sand, until the delta was created; and man, at so remote a period that we have no clue to an approximate date, occupied the fertile soil thus born of the river Nile, and that corner of savage Africa, rescued from its barrenness, became Egypt, and took the first rank in the earth's history.' During the rainy season, which lasts about four months, the river overflows its banks, and the sediment with which the waters are charged settles, adding each year a thin film of alluvial mud. The main part of the material will obviously be deposited upon the river banks, which for this reason tend to become higher than the flat region lying beyond. During floods the banks are usually seen emerging from the water, and forming long strips of land, marking the boundaries of the river's course. The Mississippi exhibits this characteristic so markedly as to have led the early geographers to describe it as a river running along the top of an extended hill or mound in a plain. Sir Charles Lyell, in his exhaustive treatment of the reproductive action of rivers, in the *Principles of Geology*, pointed out the fallacy of that view. The channel of the Mississippi forms a valley from one hundred to two hundred feet in depth, its banks forming long strips of land parallel to the course of the stream and to the swamps lying on either side (Fig. 8).

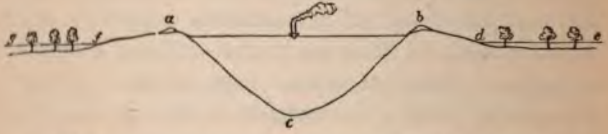

Fig. 8.—SECTION OF CHANNEL (*a*, *c*, *b*) AND SWAMPS (*f*, *g* and *d*, *e*) OF MISSISSIPPI.

a and *b* embankments above water.

When the overflow of water takes place during the season of flood, the vegetation and herbage on the banks check the velocity of the water, and acting much the part of a sieve, cause the deposition of the coarser materials first, while the finer material carried further is eventually laid down, forming a film of unctuous black soil. Thus, by the constant addition of material which decreases in quantity progressively from the edge of the stream towards the plain, the elevation of the river's banks is produced. In the soil forming the swampy flats and morasses running parallel to the stream, various forms of vegetation flourish.

Although alluvial flats such as these, and on this extensive scale are confined to the lowlands of tropical regions, similar deposits occur on a small scale in parts of the courses of all slow-moving streams, where, by reason of the gentle fall, the transporting power of the water is at a minimum. Over the broad flat plains, on which the flood waters have deposited the alluvium, the river pursues a serpentine course, which is ever slowly shifting from side to side. The river in this way tends to cut through the alluvium deposited by its waters at an earlier stage, and to give rise to fresh deposits at a slightly lower level, so that many river valleys show a succession of terraces marking previous levels of the river at flood-time. The deposition of sediment, however, is displayed in its full strength near the mouth of the river, where, under the specially favourable conditions there prevailing, an immense accumulation of sediment takes place, giving rise to new land, described under the name of a *delta*. Just as in the case of the deposition of alluvium the extent of the operation is small where the river is rapid and the rainfall is light, so under the like conditions deltas, properly so called, are not formed, or are quite insignificant. The finer material brought down by a rapid river will tend to be deposited near its mouth merely as mud-banks and sand-banks, which by the action of the tides and currents will be shifting in their character, while the coarser material will form gravel and shingle deposits in the shallower water without growing into a permanent tract of new land.

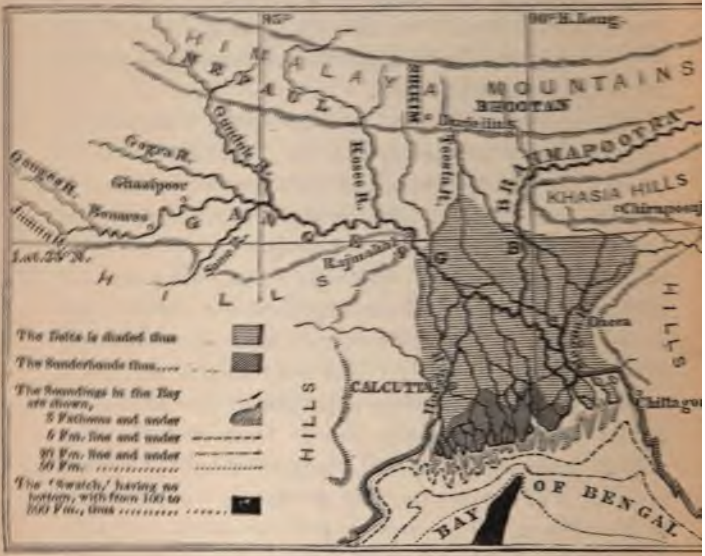

Fig. 9.—MAP OF THE DELTA OF THE GANGES AND BRAHMAPOOTRA.

We must turn to the great rivers of tropical countries for examples of deltas on a large scale. The main characteristics of these deposits will be clearly apprehended by the study of that of the Ganges and Brahmapootra. This great delta, the largest in the world, is due to the combined action of these two great Indian rivers. A glance at the map (Fig. 9) will show that the rivers are divisible into two distinct portions, of which the upper portion (in the case of the Ganges that portion above Rajmahal) is distinguished by the possession of a number of tributaries flowing into it from the surrounding drainage area, while in the lower part the river breaks up into a number of branches ramifying through the delta and opening into the sea.

The head of the delta may be defined as the point towards which the tributaries that form the branches of the upper river converge, and from which the branches of the lower river diverge, to the sea. The great stretch of lowland forming the delta through which these branches ramify forms a swampy wilderness equal in extent to the principality of Wales. The head of the Ganges' delta is 216 miles, as the crow flies, from the sea, while that of the Brahmapootra is 224 miles. These distances give an idea of the enormous extent of this delta. In this labyrinth of creeks and channels, sandbanks are constantly thrown up leading to diversions of the channels. The lowlands thus formed become overgrown with vegetation that gives shelter to the crocodilian reptiles and other wild animals that infest the Sunderbunds, and their bones must frequently have been imbedded in the delta deposits.

Some Artesian borings made at Calcutta many years ago throw a most interesting light upon the previous history of the district, for they prove that a succession of subsidences had occurred in that region. After passing through sixty feet of clay and sand the boring reached a bed of peat that clearly indicated an old land surface, and some of the plant remains were identical with forms now existing in the Sunderbunds. Below this, beds of a somewhat different character occurred, argillaceous limestone with beds of clay, marl, and sandstone, containing organic remains which were always land or fresh-water forms. At a depth of 380 feet another peaty bed was reached, showing that there had been a further extensive subsidence of the old forest-covered land. This succession of beds seems to point to a long continuance of the delta conditions, in which the area was undergoing slow depression broken at intervals by periods of repose or even of elevation. A somewhat similar condition of things was revealed by borings in the delta of the Mississippi, where down to a depth of 630 feet beds of clay and sand containing vegetable matter and shells of recent species were met with. The shells, however, in that case belonged to marine forms, such as now live in the Gulf of Mexico or swarm in the lagoons of the delta. In some of the beds large quantities of the trunks and roots of the deciduous cypress occurred. This difference between the two deltas, namely the abundance of marine forms in the Mississippi delta deposits and their entire absence from those of the Ganges and Brahmapootra, indicates a difference in the conditions under which they were deposited. It will be seen by the map (Fig. 10) that the delta of the Mississippi thrusts out a long tongue into the waters of the Gulf of Mexico, and is consequently much more subject to incursions of sea-water than the delta of the Asiatic rivers. In the case of the Mississippi, as in that of the Ganges, we have thus proofs of movements of elevation and depression, the latter amounting to several hundred feet.

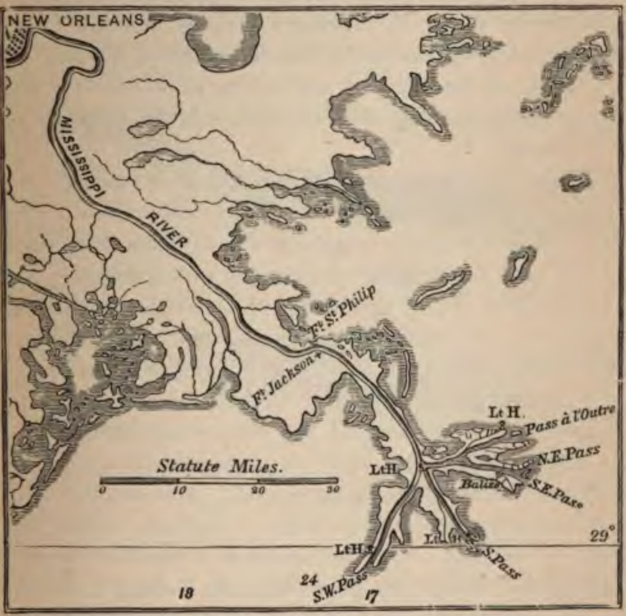

Fig. 10.—MAP OF PART OF THE DELTA OF THE MISSISSIPPI BELOW NEW ORLEANS.

The variations in the lithological character of the deposits met with in the borings above referred to, are to be explained by past geographical changes in the region. Rivers, at first quite distinct, would form independent deltas, which eventually might by growth become confluent, as undoubtedly was the case with the conjoined delta of the Ganges and Brahmapootra. The geological structure of the districts drained by the rivers usually differs, and therefore the material brought down by them necessarily varies in character and in amount. Any geographical change in the area that affected the amount of rainfall or the direction and volume of the rivers would immediately manifest itself in changes in the character of the deposit.

There is, however, another and still more obvious geographical change, namely, elevation or depression of the sea-bed, which produces a marked and easily recognised effect upon the lithological character of the deposits laid down. The law of deposition of materials on the sea-bed may be briefly stated as follows. The coarser materials, pebbles and shingle, are deposited near shore, less coarse gravel and sand further out, and fine mud further still, while beyond the point where sedimentary material reaches may occur deposits of shells and other organic remains forming limestone. This succession is illustrated by the diagrams (Figs. 11 and 12). Upon the sloping sea-bed, *A B*, the sea-level being *A C*, coarse gravel and shingle are deposited at *a*, forming a beach, sand further from the shore at *b*, mud in the deeper water beyond, and calcareous accumulations of shells or other organic remains more remotely at *B*. Suppose the area to be undergoing subsidence, so that *D E* (Fig. 12) becomes the sea-level, the coarse deposit will creep up the slope as the level rises, while the gravel and shingle at *a* will become covered with sand, the sand at *b* with mud, while the calcareous deposit—the limestone—will spread over the mud. Thus the change in the lithological character of the deposits, coarser to finer material from below upwards, would indicate a subsidence of the sea-bed, while the reverse change of finer to coarser material from below upwards would point to an elevation of the sea-bed. It will now be clear how it comes to pass that some of the newer strata of sand or coarser materials in these deltas are found to overlie an older deposit of much finer grain. We see by these variations that the law of deposition, although it may be stated in a few words, is really more complex than it seems, and more especially as to the relation between the relative age of the different groups of sediment and the fineness of their component materials. We find in these delta deposits, moreover, definitely marked divisions into strata, due to the fact that the sedimentary material is mainly brought down during the period of floods, so that there are alternations

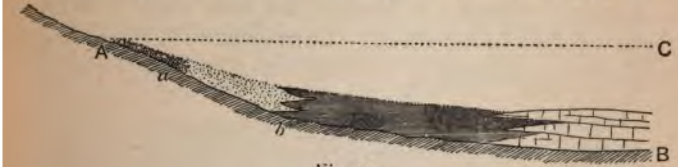

Fig 11.

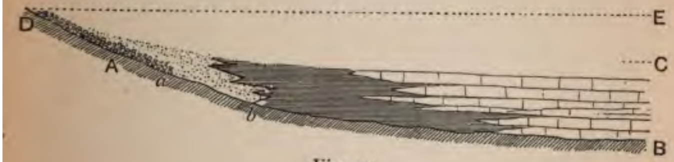

Fig. 12.

DIAGRAMMATIC SECTIONS OF SEA-BED SHOWING ARRANGEMENT OF STRATA IN A SUBSIDING AREA.

in each year of periods of rapid deposition coinciding with the season of rain, and periods of comparative non-deposition coinciding with the season of drought. Alternations of layers differing to some extent in texture and colour might be reasonably expected, and where changing currents are frequent, the beds would tend to show distinct false-bedding. The irregularity in deposition frequently exhibited by false-bedded sandstones (Fig. 13) is not difficult to explain, for sandy material sufficiently coarse to sink quickly and be swept along the bottom by currents must tend to be accumulated irregularly. Any slight obstruction will lead immediately to a deposition of sand behind it, and presently, over the top of the whole, fresh grains will be swept and deposited in front, and thus a more or less level surface established. A change in the strength of the nt, either increased by river floods or diminished

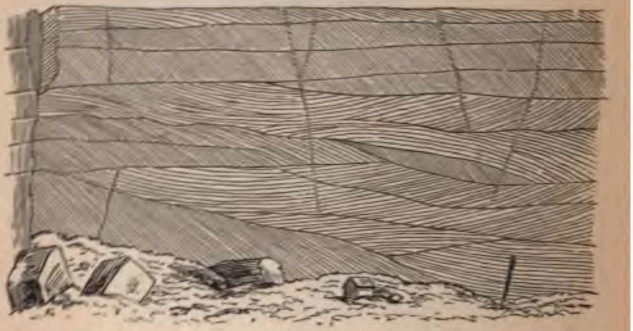

Fig. 13.—FALSE-BEDDING IN GREAT OOLITE.
(After Jukes-Browne).

during periods of drought, will obviously affect immediately the deposition of this material swept along the bottom.

While the main part of the material is carried down and deposited at the mouth of the river, to form these delta deposits in the manner described, the very finest material is frequently carried considerable distances from the coast-line and spread over deeper parts of the sea bottom. For example, the fine sediment discharged by the Nile into the Mediterranean has been observed discolouring the sea 40 miles from the shore; the muddy waters of the Ganges and Brahmapootra render the sea quite turbid near shore, and it only recovers its transparency at a distance of 60 to 100 miles from the delta, while the effect of the Amazon has been observed no less than 200 miles from the mouth of the river. Soundings in the course of the Gulf Stream, from the Gulf of Mexico into the Atlantic, have shown that very fine sand, so fine as to resemble mud, occurs on the sea-bed at a distance of 120 miles from the shore[1]. It has been estimated that the finest sediment sinks at the rate of an inch an hour, and if the rate of the flow of the Gulf Stream through the Gulf of Mexico be taken at three miles per hour, the material is carried seventy-two miles in twenty-four hours, by which time it has only sunk two feet. The fine material brought down by the Mississippi, and swept away by the Gulf Stream, must therefore be transported to great distances from the land before it reaches a final resting-place on the sea-bottom.

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[1] American *Journal of Science*, 1882, pp. 448–9.

It is a fact, however, of interest and importance in this connection that while fresh water, when slightly alkaline, is able to hold in suspension material so fine that it passes through the best filtering paper and settles so slowly that the water retains its turbidity for months, the addition of certain chemical substances leads to the rapid deposition of this excessively fine suspended material. It has recently been proved that sea-water added to turbid fresh water has this effect, so that although the rate of deposition of this finest material brought down by river-water must be extremely slow, it is accelerated by the admixture of sea-water with the river-water[2].

The explorations of the 'Challenger' have shown that round the land areas within comparatively short but varying distances which do not generally exceed a hundred miles from the shore, there is being deposited in this way the débris of the continental land. The deposits which occur between the shore and the 100 fathom line—an area of about ten million square miles—are described as *shallow-water* deposits. The materials derived from the land however are not confined to these limits, for where the slope from the continental areas is steep, blue, red, and green muds consisting of detrital matter are found at depths far exceeding 100 fathoms. (Plate VII.)[3]

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[2] *Trans. Glasgow Geol. Soc.* vol. iv. part iii. p. 257.

[3] *Report on Deep Sea Deposits, based on the Specimens collected during the Voyage of H.M.S. 'Challenger.'* By J. MURRAY, LL.D., F.R.S., and Rev. A. F. RENARD, LL.D. London: Eyre and Spottiswoode, 1891.

We now see what the final destination of the material brought down in mechanical suspension is, and how it is laid down on the sea-bed to form new strata. In the rocks that constitute the earth's crust representatives of these various deposits are to be found. Modern shingle beaches find representatives in the conglomerates consisting of rounded pebbles cemented together, while the beds of sand accumulated in shallow water by rapid shifting currents would, if upheaved and consolidated, present examples of false-bedded sandstones precisely similar to those that occur so frequently in the Coal-measures and other geological formations. The muds, composed of the more finely divided sediment which sinks slowly and is only deposited beyond the reach of currents will form uniform layers and give rise when consolidated to beds of shale, such as occur so abundantly in the rocks of the crust of the earth. These beds will usually shade one into the other, but the coarser materials will be thicker towards the shore, as in a wedge, the thin end of which will point in the direction away from the source of sediment, while the mud or clay on the other hand will be thinner towards the shore and thicker where the coarse material, such as gravel and sand, is thinnest.

CHAPTER VII.

CALCAREOUS DEPOSITS. CORAL REEFS.

HAVING dealt with the deposition of sediment brought down in mechanical suspension, we proceed to deal with the material transported in chemical solution to the sea. The analyses of different river-waters show great variations, yet broadly we may classify the materials brought down in solution by the rivers from the land as follows. The most abundant substance is usually calcium carbonate (dissolved limestone), which in the case of the Thames constitutes two-thirds of the solid material held in solution, and on an average is present to the extent of about 40 per cent. The chief other substances present in much less quantity are magnesium carbonate, silica, calcium, sodium, and potassium sulphates, and traces of sodium chloride and of oxides of iron and aluminium.

Now the analysis of sea-water gives the following composition: sodium chloride, constituting 77 per cent., magnesium chloride, magnesium, calcium, and potassium sulphates in much less quantity, and only traces of calcium carbonate and silica. The most abundant ingredient in sea-water, sodium chloride (common salt), is y present in river-water, while calcium carbonate, it down in large quantities by rivers, is present only in minute quantities in sea-water. What is the final destination of the enormous quantities of lime-salts poured into the sea annually? The answer is clear. They are taken up by marine forms for the fabrication of their shells and hard parts, which consist mainly of calcium carbonate, and there is in this way a constant removal of this material through the medium of animal life. A similar remark applies to silica, for certain animal and vegetable groups form siliceous skeletons and obtain the silica they need from sea-water. At the death of these various organisms their skeletal remains accumulate on the sea bottom and give rise to extensive deposits, calcareous or siliceous as the case may be.

Of the calcareous deposits which accumulate in comparatively shallow water the most interesting and important are those known as coral reefs. The coral-forming creatures, belonging as they do to the group of the Actinozoa, are closely allied to the common sea anemone, and their structure is extremely simple. They consist of a soft, fleshy, cylindrical body, one end of which is attached, while the centre of the free end is perforated by a mouth leading directly by a short gullet into the general body cavity, which is divided into compartments by a series of vertical radiating partitions. The mouth is surrounded by one or more circles of hollow feelers or tentacles. This fact led an early observer to describe these creatures under the name *polypus* (many-footed). The coral polyp differs from its near relative, the sea anemone, by the possession of a hard internal calcareous skeleton—the material commonly known as white coral. These soft-bodied creatures, although low in the scale of being, are endowed with the power of secreting from sea-water the carbonate of lime which goes to the making of this complicated and beautiful skeletal structure. Some of the coral forms are solitary in their character, each polyp living its own independent life. Others are compound and live in colonies, a number of polyps growing side by side, united together by a connecting fleshy substance and forming an aggregate skeletal mass of coral substance of considerable size. It is the remains of the compound forms that enter into the formation of reefs, which are but accumulations of the hard parts of dead coral and other marine organisms. The coral creatures multiply in three ways: (1) By gemmation,—buds being given out from the sides which grow up into new polyps. (2) By fission,—a polyp splitting down the middle, and each portion growing into a distinct individual. (3) By a kind of sexual reproduction—minute ova are formed in the radiating body-partitions which escape, and in due course are hatched, giving rise to tiny free-swimming creatures. These, after a short wandering existence, settle down and grow into the adult polyps, which are stationary, and, as a rule, attached to the sea-bottom. By gemmation and fission masses of coral may be formed of considerable dimensions, one generation of individuals succeeding another and contributing their remains to the slowly accumulating mass. Gradually this accumulation of coral material, intermixed with fragments of shells and remains of other marine creatures, reaches to the surface, and action of the waves fragments are broken off and so that the reef rises above sea-level. This is the manner of formation of a normal coral reef. The use of the term 'build' in relation to coral reefs has been unfortunate, for it gave rise to quite erroneous views as to their mode of formation. The popular idea of the coral building the reef as the bee builds its honeycomb is entirely without foundation. The coral polyp can only be said to build a reef in the same sense that the peat moss and other vegetation may be said to build the peat which consists of their accumulated decayed remains. A coral reef is never anything more than an accumulation of the hard parts of dead coral creatures, together with shells and skeletons of other marine organisms cemented together by calcium carbonate dissolved from one part and deposited in another.

The study of the distribution of these reef-forming polyps leads to certain important and interesting conclusions. The group of solitary corals whose remains do not form reefs occur in all parts of the world. They have an almost universal distribution, and are found alike along shore lines and in the deep ocean. They have been dredged in the North Sea off the Shetland Islands, in the Atlantic off the coast of France and Spain, in the Mediterranean, and in different parts of the Pacific. The distribution of the other group of reef-forming corals is much more limited, and appears to be determined by the following three conditions.

(1) Reef-forming corals can only flourish in water whose temperature does not fall below 70° F. and whose annual range is not greater than 12° F. Bermuda, the coral reef most distant from the Equator (Lat. 32° north), is the only apparent exception; the temperature there

sometimes sinks to 66° or 64° F. and the annual range is greater than 12° F. This limit of temperature confines coral reefs to the regions between about Lat. 30° north, and Lat. 30° south. (Plate VI.)

(2) They are also restricted to those portions of the sea-bottom remote from estuaries of large rivers; fresh water and muddy water being fatal to them.

(3) They are not found at greater depths than about 150 ft., that is about 25 fathoms.

Recent investigations show that temperature is a most important element in the development of all forms of marine life, and it has been observed that coral reefs are most perfectly developed in those regions where the temperature is highest and the annual range least. The curious absence of coral reefs on the west coasts of the great continents, especially Africa and South America, is dependent upon this circumstance, for these western coasts are washed by waters from polar regions, while the 'Challenger' observations have shown that towards the eastern coasts of the continents the warm layers of surface water are thicker and of a higher temperature, affording the conditions favourable for the growth of rich coral life. No coral reefs occur in temperate or polar regions, although, as we have already pointed out, species of solitary coral occur, but not the reef-forming group.

This intimate connection of temperature with richness of life, was further emphasised by the sounding operations of the 'Challenger,' for it was found that in descending into deeper water in equatorial regions the amount of carbonate of lime secreted by living forms decreased with the depth. The temperature soundings have everywhere

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shown a decrease from the surface to the bottom of the sea, the temperature all over the deepest parts being somewhere about 32° F, the freezing point of fresh water. It has been found that the pelagic organisms collected at the surface decrease in number, and develop shells less massive in build in proceeding from equatorial regions polewards. So marked is this influence of temperature that Dr. John Murray has pointed out that even in temperate seas more calcium carbonate is secreted in summer than in winter. His estimate of the amount of this substance that exists in the shells of various pelagic forms in tropical waters is fifteen tons in a mass of water one square mile in extent and one hundred fathoms in depth, and he states that in the samples of deep-sea deposits collected by the 'Challenger,' the average percentage of calcium carbonate in the whole of the deposits covering the floor of the ocean was 36·83, of which he estimates that 90 per cent. is derived from surface organisms, the remainder having been secreted by forms that live at the bottom.

The comparison of the analyses of river-water and sea-water given on an earlier page, shows that not only is calcium carbonate present in far larger quantity in river-water than in sea-water, but that other calcium salts are transported in considerable quantities into the sea. The very interesting experiments of Murray and Irvine, recently published, have demonstrated that living creatures favour the conversion of chloride, sulphate and phosphate of calcium into the carbonate[1]. Their investigations seem to indicate that the whole of the calcium salts in sea-water may by the action of living

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[1] They describe experiments in which hens were shut up in a wooden building where no lime was obtainable, and in a few days

the eggs ceased to have a calcareous shell. The sulphate, phosphate, nitrate and silicate of calcium were then successively added to the food, and out of all these salts calcareous shells of calcium carbonate were formed. When magnesium and strontium salts were given instead of calcium salts no effect was produced, and the egg-shells remained membranous. Experiments were similarly made with artificial sea-water from which calcium carbonate was excluded, but which contained other lime-salts. In this water crabs were able to produce their usual skeleton of calcium carbonate, and the water, which was quite neutral before the crustaceans were introduced, became afterwards distinctly alkaline, owing to the decomposition of the effete nitrogenous products and the formation first of ammonium carbonate and eventually of calcium carbonate. Other similar experiments led to the conclusion that the process involved first the secretion of ammonium carbonate which reacted on the lime-salts in the water giving rise to calcium carbonate. Dr. Murray points out that if this ammonium carbonate be a stage in the formation of urea, it is not unnatural to suppose that in shell-forming animals the shell formation may take place at this stage without the formation of urea at all. Waters from different parts of the ocean were tested with a view of ascertaining what proportion of ammonia was present: (i) in the albuminoid form due to the decomposition of effete matters; and (ii) saline ammonia due to vital action. The following interesting results were made out.

1. In the sea-water collected among the coral atolls of Louisiade Archipelago there was:—

Saline Ammonia ·048.
Albuminoid Ammonia ·018.

2. Water collected by the 'Challenger' in the North Atlantic, Lat. 30°20′ N. Long. 36°6′ W.:—

Saline Ammonia ·026.
Albuminoid Ammonia ·016.

3. Water from the German Ocean near land:—

Saline Ammonia ·13.
Albuminoid Ammonia ·13.

Thus it is seen that the greatest quantity of ammonia in the form organisms be converted into the carbonate, and so assume a form suitable for the formation of their shells and skeletal parts.

Dr. Murray has further pointed out that this view explains a difficulty which has long been felt, and was strongly put by Bischof in his Chemical and Physical Geology, namely, the enormous amount of sea-water which would presumably have to pass through an organism to furnish the amount of calcium carbonate necessary for its shell. 'It seems probable,' says Dr. Murray, 'that the reactions indicated by our experiments render the whole of the lime-salts in sea-water available for coral polyps to build up their structures. In polyps, which unlike the higher animals, have no true circulatory system, and where the animal is immersed in sea water, it is hardly possible to account for the enormous secretion of carbonate of lime in the manner indicated by Bischof, but if the conclusion we have arrived at be correct, and such animals in place of secreting urea secrete carbonate of ammonia, then we have a perfectly reasonable explanation of the phenomenon of coral formation.'

The accumulation of coral material in the form of great reefs and islands is taking place on an extensive scale in tropical regions, especially of the Pacific and

that is due to the action of living organisms is present in those waters where the most abundant animal life exists, that is in the waters of the coral atolls. It was least in the waters where active life was at its minimum, viz. in the German Ocean. *Coral Reefs and other Carbonate of Lime Formations in Modern Seas,* by J. MURRAY and R. IRVINE, *Proc. Roy. Soc. Edin.*, vol. xvii. p. 79 (1889), and *Nature,* vol. 42, p. 162.

Indian Oceans. The Great Barrier Reef of North-Eastern Australia extends for a thousand miles from north to south, with a breadth varying from 20 to 70 miles. Over thousands of miles in the Pacific the islands are almost exclusively of coral formation. In the case of some of these barrier reefs and atolls the coral accumulation seems to rise from depths of many hundred or even thousand feet, although the depth at which the coral polyps can flourish does not exceed about 150 feet. This circumstance, together with the curious shape and structure of atolls, led Darwin to put forward his famous theory of coral reefs [2]. To make clear the nature of the problem which he attempted to solve, a short description of the three different kinds of reefs is necessary.

(1) A Fringing Reef stretches out from the shore as a prolongation of the beach covered by a lagoon of shallow water. A reef of this kind surrounds the island of Mauritius. The beach is continued outwards into a kind of low terrace covered by shallow water, while about a mile from the land a white line of breakers marks the seaward limit of the reef, at which point the depth is not greater than about 150 feet. The reef extends around the whole circumference of the island except at two or three places where the coast is precipitous, and where the coral would presumably have no foundation on which to become attached. A breach also occurs opposite the mouth of every river and stream by reason of the pollution of the water, which is fatal to coral life. It is usually asserted that the coral polyps

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[2] *Structure and Distribution of Coral Reefs*, by CHARLES DARWIN.

flourish most vigorously on the outer margin of the reef where they are most exposed to the wash of the sea, and this fact is explained by the larger supply of nutriment furnished to the polyps in that position by the sea currents. Dr. Sydney Hickson has shown that this at any rate is not universal, for in Celebes he found coral life to be poor in the parts of the reefs which projected furthest into the sea. He attributes this poverty of growth to the rapidity of the currents, which swept along the food of the polyps too rapidly for easy capture [3]. Beyond the reef where the depth is greater than 150 feet living coral has not usually been found.

(2) A Barrier or Encircling Reef differs from a fringing reef in being separated from the shore by a lagoon of great width and considerable depth, while soundings outside show depths far exceeding those in the case of a fringing reef. The term 'barrier reef' was first applied to the gigantic reef that skirts the East Coast of Australia and forms the most wonderful accumulation of coral rock in the world.

(3) The third and in some respects the most interesting group of coral reefs are known as Atolls. An atoll is a more or less complete ring of coral land usually broken so that the atoll consists of a number of islands arranged in an oval or circular manner, and not of one island. There is a lagoon in the centre, while as in the case of a barrier reef the depth outside the atoll is frequently very great. All these coral islands are low, rising only a few feet above sea-level, for they

[3] *A Naturalist in North Celebes*, by SYDNEY J. HICKSON, D.Sc. p. 24. Murray.

have been formed by the action of the waves throwing up fragments of broken coral. Some are of great extent, and there are vast areas in the Indian and Pacific Ocean in which every single island is of coral formation. The Radack group of atolls is an irregular square 520 miles long and 24 broad. The Low Archipelago is an oval 840 miles in its longer and 420 miles in its shorter axis. Taking the islands between these we have a strip of ocean 4000 miles long in which not a single island rises more than a few feet above sea-level, that is just to the height to which fragments of coral might be piled up by the action of the waves. A most interesting question here presents itself. How is the formation of these barrier reefs and of atolls to be explained, seeing that the coral polyps cannot flourish at greater depths than 150 feet, while these great coral accumulations appear to rise from depths of many hundred feet?

Darwin's theory, which may be briefly put as follows, offered a very simple solution of the problem. He argued that if coral polyps were introduced into a new area, they would settle on the sloping sea-bed below high water mark down to depths of 25 fathoms, and in time by accumulation a Fringing reef would be formed. If a subsidence of the area now took place, so slowly that the growth of the coral reef was able to keep pace with the depression, the Fringing reef would become an Encircling or Barrier reef. If the subsiding land were an island and the subsidence were continued, the Encircling reef would eventually with the disappearance of the land become an Atoll. According to this theory Atolls are monuments marking the positions of the high peaks of a submerged land-area.

The detailed discussion of this question in the light of the recent important contributions of Dr. Murray and others, would carry us outside the purpose of this volume[4]. Sufficient has already been said to make clear the mode in which the lime-salts carried by rivers in invisible solution to the sea assume the visible form of the carbonate and accumulate to form calcareous deposits through the intervention of coral life. Some of the most characteristic limestone beds in the geological series, such as the Wenlock, Carboniferous, and Jurassic limestones, are in part old coral reefs, and for a knowledge of the conditions under which they were formed we must turn to the study of the formation of modern coral reefs.

Large, however, as are the coral accumulations referred to, they are insignificant in comparison with the vast deposits of shells of pelagic organisms which cover millions of square miles of the deep Atlantic and Pacific, and which we now proceed to describe.

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[4] *Structure, Origin and Distribution of Coral Reefs and Islands*, by J. MURRAY, *Nature*, vol. 39, p. 424 (1889).

CHAPTER VIII.

DEEP-SEA DEPOSITS.

OUR knowledge of the nature of the deposits which are forming in the deeper oceanic waters, and of the character and contour of the sea-bottom is of recent origin. Until about thirty years ago, owing to the difficulty of taking soundings in deep water, no systematic investigation of the unknown region covered by the great oceans had been attempted. It was popularly supposed that animal and vegetable life did not exist below depths of a few hundred fathoms, for it was assumed that the absence of sunlight, the low temperature, and the stupendous pressure which must prevail in the deepest parts of the sea, precluded the possibility of life such as we know at the surface. The ocean depths were pictured, as a 'wide, grey, lampless, deep, unpeopled world.' Recent deep-sea explorations have shown how mistaken these assumptions were. Even at the great depths, where apparently the conditions are most unfavourable, life exists of rich and varied character and exhibiting features of great interest. It is, however, only with those results of recent explorations that bear strictly upon geological questions that we have here to deal.

One of the first systematic attempts to explore the deep sea by English naturalists was made by Dr. W. B. Carpenter and Sir Wyville Thompson in 1868. They succeeded in obtaining from the Admiralty the use of an old paddle-steamer, the 'Lightning,' in which they made their first explorations in British waters, and proved that it was possible to sound and dredge with as great accuracy at a depth of 2,400 fathoms (nearly 3 miles) as at 100 fathoms.

The chief difficulty in the way of successful deep-sea exploration in earlier times had been the imperfection of the sounding apparatus. The ordinary 'lead,' used in shallow water by vessels seeking safe anchorage, had proved quite useless in deep water. This primitive instrument consists of a block of metal 18 inches or 2 feet in length, weighing from 80 lbs. to 120 lbs., attached to a line marked into fathoms by pieces of bunting. In taking soundings the lead is lowered over the side of the ship until a check is felt by the instrument touching bottom; the length of line run out is then noted and gives the depth.

This simple apparatus served well enough for rough soundings taken in shallow water, but at great depths it was found impossible to detect the check when the bottom was reached, and as the line was always liable to continue running out under the action of undercurrents, no dependence could be placed upon the observations taken. To overcome these difficulties it was necessary to increase the size of the weight and diminish the thickness of the line. But this could only be done within narrow limits, for the line needed to be sufficiently strong to bear the strain of hauling the weight up to the surface. The invention by Lieutenant Brooke, of the United States Navy, of an ingenious con-

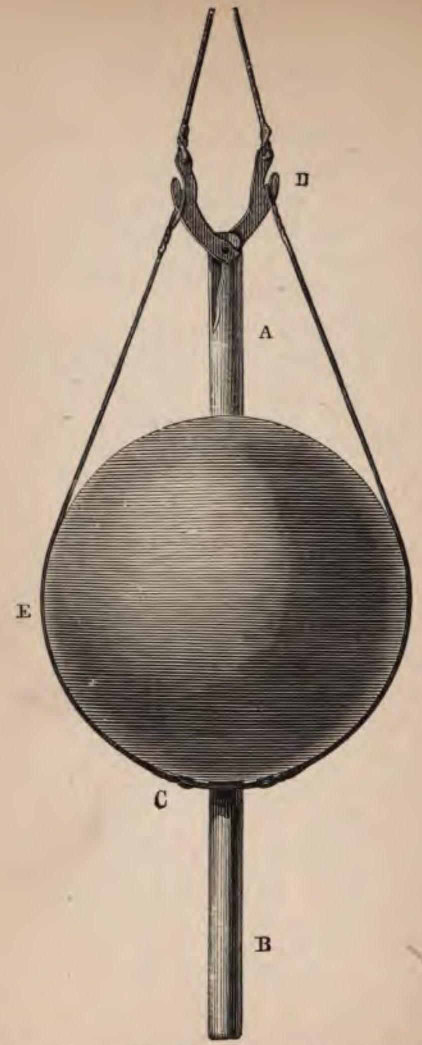

Fig. 14.—BROOKE'S DEEP-SEA SOUNDING APPARATUS
Ready for taking a sounding.

trivance by which the weight could be detached when the bottom was reached, solved this problem, and opened the way to extensive explorations of the deep sea. This apparatus in principle was simplicity itself, and consisted (Fig. 14) of a 64 lb. shot E, cast with a hole through it for the reception of an iron rod A, which had a chamber B at the lower end, and two moveable arms hinged to the upper end. Each arm was perforated with an eye to which were fastened two cords by which the rod was suspended, and bore also a projecting notched tooth D, for the purpose of holding the loops of the leather sling C that supported the shot. When the apparatus was ready for sounding it was in the position shewn in Fig. 14. On striking the bottom, the end of the rod was driven into the deposit, which filled the chamber B, the two jointed arms fell (Fig. 15); the loops of the string slipped from the teeth, and the rod passing through the hole in the shot came up alone with its enclosed sample of the deposit. Numerous modifications of Brooke's principle, but less cumbrous, and more suitable for general purposes have since been constructed, and successful soundings have been taken at depths of over five miles.

The results obtained during the short cruise of the 'Lightning' were so interesting that in the following year another vessel, the 'Porcupine,' was despatched on a more extended cruise to the north-west of Ireland, and southwards as far as the Mediterranean. During this time other countries were not idle, and important contributions were made by American, Norwegian, and Swedish explorers. The extreme interest of these results

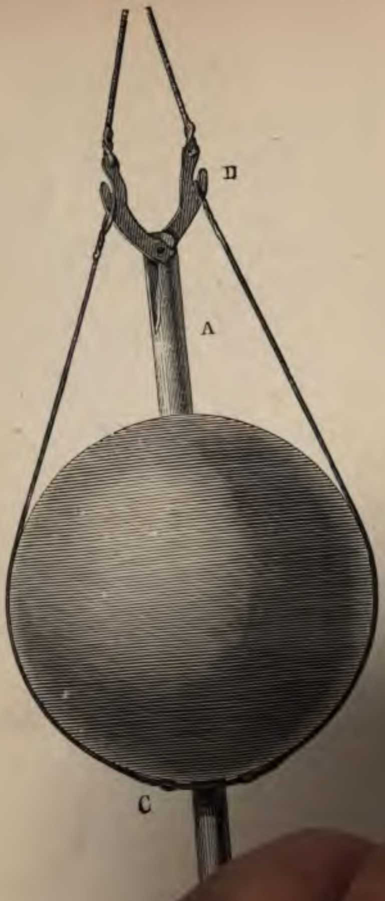

Fig. 14.—BROO

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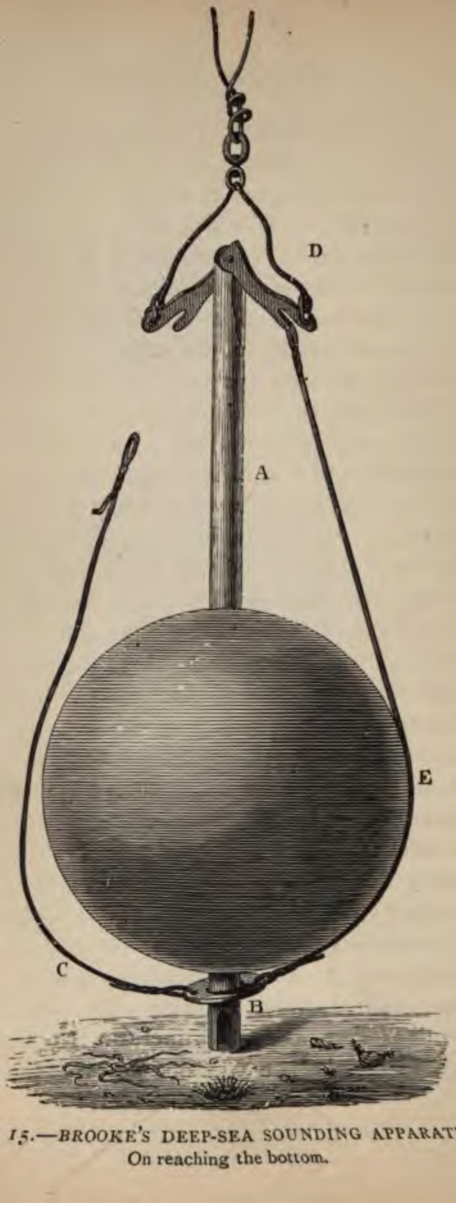


Fig. 15.—BROOKE'S DEEP-SEA SOUNDING APPARATUS.
On reaching the bottom.

directed attention to the deep sea as a new and fruitful field of investigation, and in 1872 the 'Challenger' was fitted out by the British Government for a three years' exploring cruise. The ship was furnished with the newest scientific appliances, and carried a staff of scientific observers prepared to deal with different departments of research. From the day she set sail on December 21, 1872, until her return on May 4, 1876, over 30,000 miles were traversed and 504 soundings taken, in addition to about 200 dredgings and trawlings. The deepest sounding taken was 4575 fathoms (about 5 miles) south of the Ladrone Islands, while a depth nearly as great was reached off the coast of Japan. The materials brought back have taken many years to work over, and a large number of important reports and memoirs on the various branches of study which occupied the scientific staff have appeared.

The main features of the results, in so far as they throw light upon the nature and distribution of the deposits now being accumulated in the abysmal regions of the great oceans, are as follows.

Around the shores of continental lands and islands, as was pointed out in an earlier chapter, deposits consisting of fine detrital matter from the land areas, are being laid down. The muds are sometimes quite free from organisms; in other cases the remains of foraminifera, molluscs, polyzoa and other forms are present, sometimes to the extent of 50 per cent., together with siliceous remains of diatoms and radiolaria. As a rule near shore the calcareous remains are those of coast organisms, which are replaced in the deposits further out to sea by pelagic forms, which increase in number as the distance from shore becomes greater, while the mineral matter at the same time becomes finer in texture and less in quantity until it eventually passes into a true calcareous deep-sea deposit of Globigerina ooze. Between depths of about 300 fathoms and 2,500 to 2,800 fathoms in temperate and tropical zones, the sounding apparatus brought up this white or grey ooze composed of calcareous remains of pelagic foraminifera, such as *Globigerina bulloides.* In some localities the deposit was found to contain as much as 95 per cent. of calcium carbonate (carbonate of lime), in other cases the proportion fell as low as 40 per cent. Chemical analysis of the ooze has shown the presence, in addition to calcium carbonate, of calcium phosphate and calcium sulphate, magnesium carbonate, oxides of iron and manganese and argillaceous matter, together with the remains of siliceous organisms which formed, in some samples, as much as 20 per cent. of the deposit, while in others they were only present in very small quantity.

As far back as 1853, when Lieut. Brooke's sounding apparatus was first introduced, small quantities of a similar deposit had been obtained from the bottom of the North Atlantic, between Newfoundland and the Azores, at depths of about 1500 fathoms. The samples were submitted to careful microscopical examination, and were found to consist of the remains of these foraminiferal organisms. A few years later, when the work of laying the telegraph cable across the Atlantic was undertaken, further soundings were made which furnished additional samples of Globigerina ooze, and confirmed the conclusions to which the earlier examinations had led. The systematic series of soundings taken by the 'Challenger' have shown how widespread is the distribution of this deposit over the sea-bottom between the depths stated, for it is found not only in the Atlantic, but also in the Pacific and Indian Oceans, in temperate and tropical latitudes.

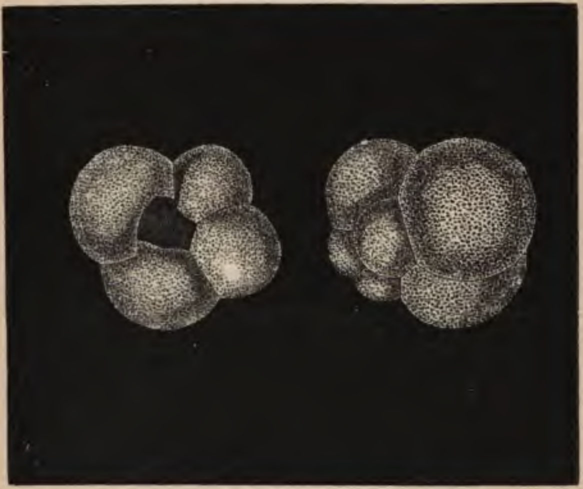
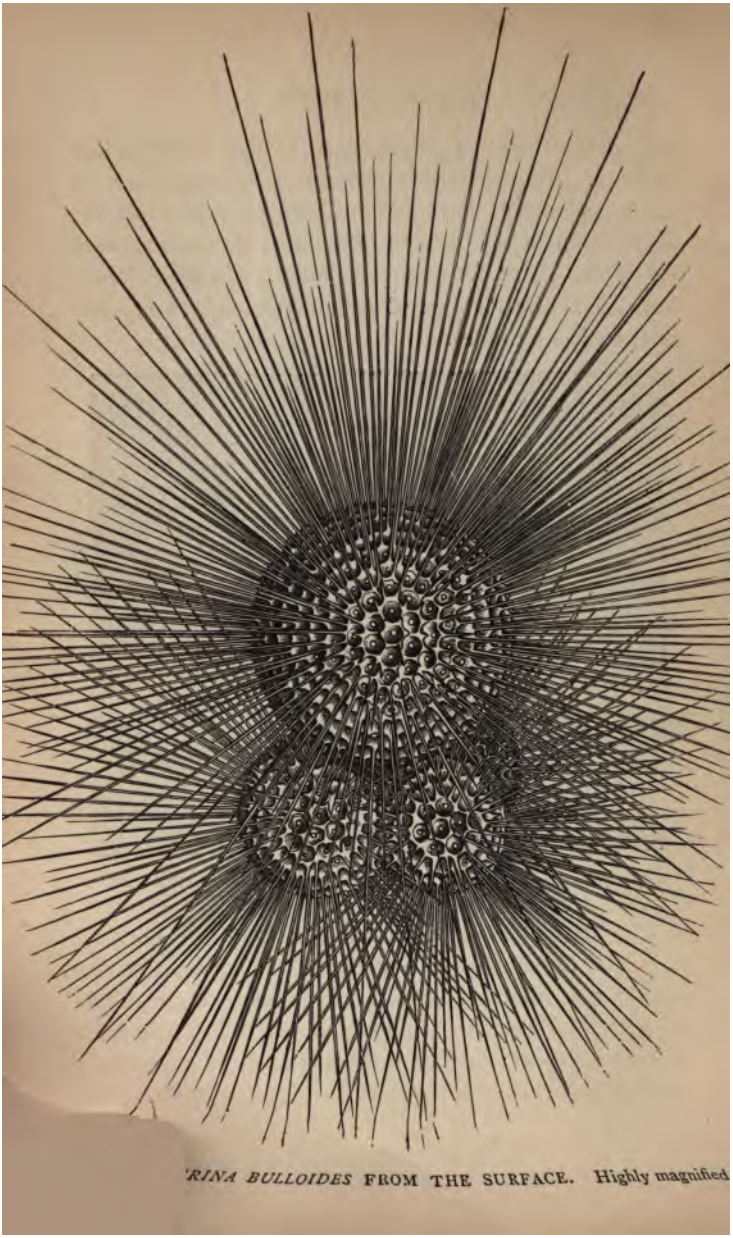


Fig. 16.—*GLOBIGERINA BULLOIDES* FROM DEPOSIT ON SEA-BOTTOM. Highly magnified.

The shell of *Globigerina bulloides*, the most abundant organism in the deposit, is microscopical in size, and consists of a series of globular chambers increasing regularly in size, and arranged in such a way that while each chamber communicates with its neighbour it partially embraces it (Fig. 16). The shell-walls are perforated by



RINA BULLOIDES FROM THE SURFACE. Highly magnified

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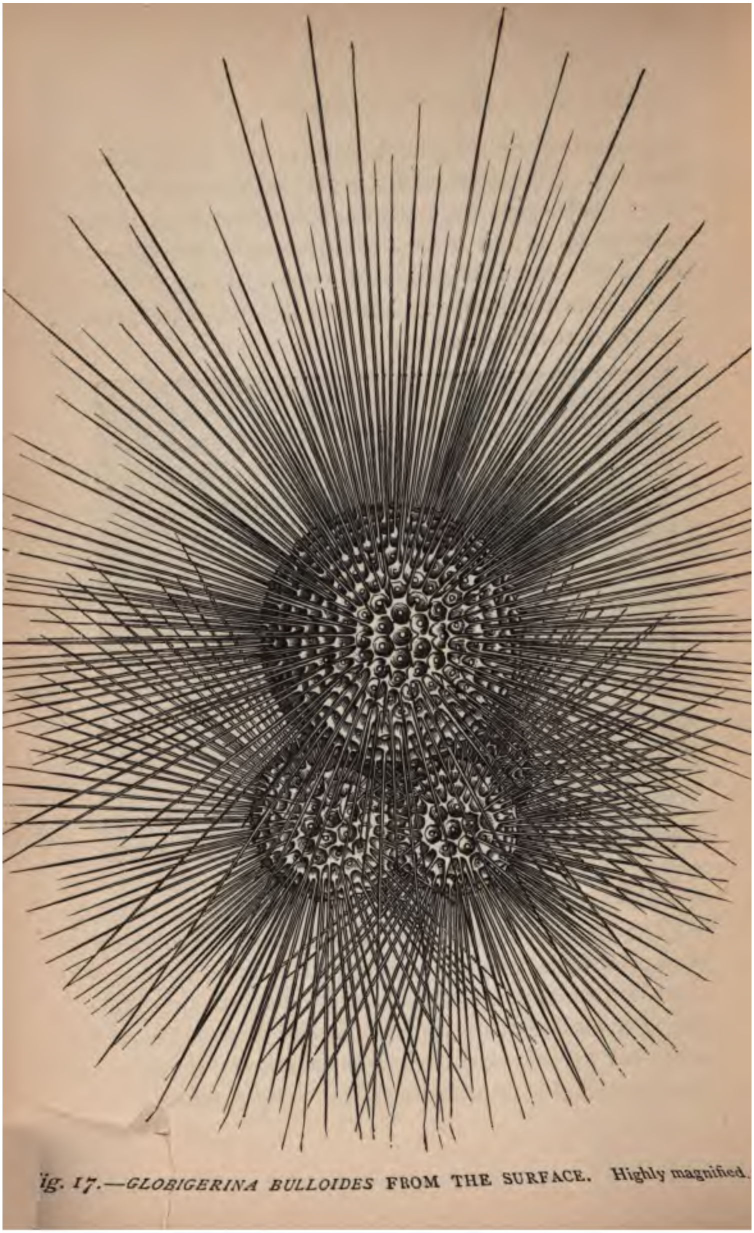

ig. 17.—*GLOBIGERINA BULLOIDES* FROM THE SURFACE. Highly magnified.

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minute pores or foramina, to which the name of the group—*Foraminifera*—is due. In the living state the Globigerina shell presents a very different appearance, as will be seen by Fig. 17. Each of the minute pores penetrating the shell-wall is surrounded by a raised crest, those of neighbouring pores coalescing into a kind of hexagonal network over the surface of the shell, which gives to the pores the appearance of lying at the bottom of little hexagonal cups. From the angles of these hexagons proceed long delicate flexible spines, which are sometimes four or five times the length of the diameter of the shell. They form sheaves of long transparent needles crossing one another in different directions and producing a highly beautiful effect. Their fragility however is so great that they break off at the slightest touch, and are never found on the dead shells forming the bottom ooze. The living creature is of very simple structure. It consists of a speck of jelly-like protoplasm which has no parts or organ, of any kind, but is endowed with contractility and with the power of fabricating this delicate shell of exquisite beauty.

Other allied forms of Foraminifera, as well as shelly remains of forms much higher in the scale of life, such as the Heteropoda, and Pteropoda occur together with Globigerina. Certain curious bodies described as Coccoliths and Rhabdoliths, and believed to be the armature of calcareous algæ, are also present. In addition to these various forms there occurs in the ooze a large quantity of granular calcareous matter which fills the shells and the interstices between them, forming as it were a kind of matrix, in which they are embedded.

The question raised by early observers as to whether Globigerina and its allies lived at the bottom or inhabited the surface waters, has been definitely settled in favour of the latter view. The observations of the 'Challenger' staff have established beyond question the fact that these delicate forms live exclusively in the surface waters and down to a depth of five or six hundred fathoms. The remarkable coincidence of the surface distribution of the living Globigerina with the bottom distribution of the Globigerina ooze, afforded strong presumption in favour of that view. The living shells are never found in polar surface waters, and the Globigerina ooze similarly does not occur on the sea-bed in polar regions. No specimen of the shell filled with the living protoplasm has ever been dredged from the bottom, although it is clear that the bottom conditions are not unfavourable to life, for allied species are frequently brought up in the living state from great depths; but these bottom forms differ in many respects from Globigerina, and in particular possess thicker shells. It appears therefore that over certain regions of the Atlantic, Pacific, and Indian Oceans, in the intermediate zone between the Arctic and Antarctic circles, a never-ceasing fine rain of delicate foraminiferal shells is falling gently from surface to bottom, constantly adding to the thickness of the calcareous deposit, with which the sea-bottom is covered.

In polar regions the place of the Globigerina ooze is taken by Diatom ooze of a pale straw-colour, composed of the frustules of Diatoms. These organisms, which like Globigerina are extremely minute are classed as siliceous algæ. The 'Challenger,' on passing from tropical regions in the Indian and Atlantic Oceans to Antarctic regions, found that the change in the bottom deposit coincided with the change in the character of the surface organisms. The Pteropods, Heteropods, and Foraminifera characteristic of the tropics gradually disappeared, giving place to Diatoms and to Radiolarians of species found in colder latitudes. The Diatoms were present in such abundance that the tow-nets were often filled with a slimy mass of these minute forms, and the Globigerina ooze was found to pass by insensible gradations into Diatom ooze, which forms a band of deposit surrounding the Antarctic Continent. The Diatom ooze in its turn, when traced towards the land, passed into a blue mud composed of detrital matter from the Antarctic land worn away by the action of ice[1].

If the map (Plate VII) be examined, the distribution of these various deposits over the sea-bottom will be seen at a glance. This map should now be compared with Plate I showing the depths, when a curious relation will be perceived to exist between the depth and the nature of the deposit. The calcareous deposit of Globigerina ooze is not found where the depth exceeds 2800 fathoms. At greater depths the deposits covering the sea-bed are entirely different in character. In conducting a series of soundings from regions under 2000 fathoms to those over 3000 fathoms, the 'Challenger' staff found that the calcareous Globigerina ooze passed gradually into a pure red clay, which occupied the sea-bottom at depths exceeding from 2500 to 2800 fathoms. This deposit consists of exceedingly fine clayey matter of a red or brown colour, due to the presence of the higher oxides of iron and manganese. It is described as plastic and greasy to the touch, and forms when dry coherent lumps requiring considerable force to break them. The ultimate mineral particles of this clay are composed, according to Dr. Murray, of pumice and other volcanic matter which, owing to their relatively recent deposition, have not undergone great alteration, while it contains an excess of free silica due to the presence of siliceous organisms. In the deeper Red Clay areas of the Pacific Ocean a considerable quantity of manganese peroxide was found in the form of nodules around the teeth of sharks and the earbones of whales, which occurred in great quantity. It is a curious circumstance that these were the only portions of the skeletons of these creatures found in the deposit, and no other organic remains were present in the typical Red Clay, beyond now and then a few broken fragments of foraminiferal shells. It is interesting to note that the transition from the calcareous deposit to the Red Clay was slow and gradual. As soundings were taken successively from depths of 2250 fathoms, where typical Globigerina ooze occurred, into deeper regions, the shells composing the ooze began to assume a rotten look, and the deposit to take a more brownish colour. These changes became more and more marked with increasing depth, till at about 2500 fathoms pure Red Clay was found almost free from calcareous material. The frequency with which the changes occurred in the numerous soundings made by the 'Challenger,' established beyond question the existence of an intimate relationship between depth of water and character of deposit, which was so constant that it was found possible to predict with certainty the nature of the bottom as soon as the depth was ascertained.

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[1] *Marine Deposits in the Indian and Antarctic Oceans*, by JOHN MURRAY, LL.D., F.R.S., *Scottish Geographical Magazine*, Aug. 1889.

The characteristics of this remarkable clay deposit are so peculiar that the question of its origin offered a problem of the greatest interest, which early occupied the attention of the 'Challenger' staff. Whence had the materials of the clay been derived? Why was it destitute of the remains of Globigerina and other pelagic forms which constituted the bulk of the ooze? These organisms were known to inhabit the surface waters of the ocean over the whole temperate and equatorial regions, and yet in adjoining tracts in the Atlantic and Pacific, where the surface waters overhead of both alike teemed with foraminiferal and molluscan life, the shells in the one tract sank to the bottom and accumulated as a calcareous deposit, while in the adjoining tract, a few hundred fathoms deeper, only a sprinkling, amounting to two or three per cent. of the myriads of shells that inhabited the surface water, ever reached the sea-bottom. What became of these vanished shells? How and why were they intercepted in sinking from the surface to the deep-sea bed? These were some of the questions which had to be considered. The first solution which naturally suggested itself was that the clay was the most finely divided part of the detrital matter brought down by rivers from the land, and distributed by ocean currents into the deeper parts of the sea. The uniform character however of the formation over wide areas, and the fact that it was absent in the shallower portions between the Red Clay areas and the shore, where on the supposition that it was derived from the land, it presumably ought to be most abundant, seemed to render this explanation untenable. There was the further fact of the absence of calcareous organism from the deposit, upon which this explanation threw no light. There was obviously only one mode of accounting for this absence of shells, they must have been dissolved in their passage from the surface to the bottom. This explanation opened up a number of interesting questions. Why did the solution occur only at great depths? Here was a curious circumstance that foraminiferal shells would sink down to 2250 fathoms apparently uninjured, and in the next two or three hundred fathoms undergo complete solution. To this question the soundings of the 'Challenger' have furnished an answer, for they have proved that the disappearance of the more delicate forms really begins at depths less than 2250 fathoms. The Heteropods, Pteropods, and more fragile Foraminifera, for instance, have almost entirely disappeared at depths of 1800 to 2000 fathoms, so that it seems clear that the solvent action begins to be exerted upon the shells when life ceases, and is continued until their complete disappearance. The distance therefore through which shells sink before solution is complete, depends in part upon the density and the resistibility of the shells themselves, although there seems to be little doubt that the solvent action is more marked at great depths.

Samples of Globigerina ooze were carefully washed and submitted to the action of a weak acid by Mr. Buchanan, the chemist of the 'Challenger' Expedition, who found that after the calcium carbonate had been dissolved, there remained behind about one per cent. of a reddish clay, identical in composition with the Red Clay of the deep sea. This led the late Sir Wyville Thompson to speak of the Red Clay as the insoluble residue—the ash as it were—of the calcareous organisms which formed the Globigerina ooze after the calcareous matter had been removed by solution [2].

The observations of Dr. Murray have further elucidated this point by showing that the material of the Red Clay is in great part derived from the decomposition of volcanic products. The soundings of the 'Challenger' have established the fact, that over a great part of the sea-bed pumice and other volcanic materials are abundant. Fragments of pumice were constantly dredged at great distances from land. The surface portions of these fragments had been decomposed into a soft clayey material. The Red Clay was further found to contain minute black and brown metallic spherules, possessing magnetic properties, which Dr. Murray describes as 'cosmic dust,' and believes to be of meteoric origin. There can be little doubt that the fine material, which when in quantity forms the Red Clay, is widely distributed over the sea-bottom, but in the shallower parts the calcareous material of the Globigerina ooze is so largely in excess, that it forms the dominant feature of the deposit, and it is only when this calcareous matter is removed by solution that the presence of the red clay becomes manifest.

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[2] *The Atlantic*, by Sir Wyville Thompson, p. 229.

Passing into still greater depths of over 4,000 fathoms, another interesting change in the character of the deposit is found to occur in the Pacific Ocean. With increasing depth, organic remains begin again to appear in the deposits more and more abundantly, and the Red Clay at 4,000 fathoms or thereabouts is found to contain so large a proportion of the delicate spicules and hard parts of siliceous Radiolaria, as to give to the deposit the name of *Radiolarian ooze.* The passage from the one to the other is gradual, and Dr. Murray fixed the arbitrary proportion of 25 per cent. of siliceous organisms as that which would entitle the deposit to be called *Radiolarian ooze.* We have here a very curious condition of things. At depths of from 3,000 to 3,500 fathoms, occurs typical Red Clay—an inorganic deposit, destitute of organic remains. On either side, in the shallower and in the deeper water, the deposits are largely organic in character. Thus on sounding from 3,500 fathoms into shallower water, calcareous organisms begin to appear until the clay passes into the characteristically organic deposit of Globigerina ooze. Taking soundings into deeper water in like manner, organic remains begin to increase in number until the Red Clay passes into Radiolarian ooze; but in this case the organisms instead of being calcareous are siliceous.

It may well be asked, why these Radiolaria are so abundant in the deposit at depths of 4,000 fathoms and while at smaller depths they constitute no important proportion of the deposit. The explanation suggested by Dr. Murray seems to meet the difficulty completely. He pointed out that while the Globigerina and its allies are confined to the superficial layers of oceanic waters there is every reason to believe that the Radiolaria flourish throughout from surface to bottom. The Radiolarian remains, therefore, accumulating on the sea-bottom must increase in quantity proportionally with the increase of depth. As we have seen, the calcareous shells are removed in these deeper waters by solution, and there is nothing therefore to mask the presence of the Radiolaria.

In view of the fact that these siliceous forms are so widely distributed, it is noteworthy that certain marine deposits are entirely free from their remains, and this can only be accounted for on the supposition that the siliceous skeletons are like the calcareous under certain conditions, dissolved by the sea-water. Dr. Murray has pointed out[3] that an examination of the skeletons in certain deposits showed that this process of solution is going on. The skeletons have a rotten crumbly look similar to that taken on by the Globigerina remains at depths of between 2,250 and 2,500 fathoms.

The following interesting table setting out the comparative average composition of these three deposits, Globigerina ooze, Red Clay, and Radiolarian ooze, is compiled from figures given in the Challenger Reports.

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[3] *Marine Deposits in the Indian and Antarctic Oceans. Scottish Geographical Mag.* August, 1889.

		Globigerina Ooze.		*Red Clay.*		*Radiolarian Ooze.*	
Calcium Carbonate (Carbonate of Lime)	Pelagic foraminifera	53·10		4·77		3·11	
	Bottom living „	2·13		0·59		0·11	
	Other organisms	9·24		1·34		0·79	
			64·47		6·70		4·01
Residue	Siliceous organisms	1·64		2·39		54·44	
	Minerals . . .	3·33		5·56		1·67	
	Fine washings .	30·56		85·35		39·88	
			35·53		93·30		95·99
			100·00		100·00		100·00

It will readily be realised that the process of accumulation at these abysmal depths must be extremely slow. The presence of the sharks' teeth and cetacean ear-bones in the Red Clay deposit of the Pacific, in such enormous numbers clearly implies this. There is no reason to believe that these creatures are more abundant in that part of the ocean than elsewhere. The great quantity of these remains therefore represent untold generations of sharks and whales whose skeletons have yielded to the solvent action of the water, leaving only those denser portions represented by the teeth and the hard resisting earbones to testify to their former existence. So slowly has the Red Clay accumulated that during the great lapse of time represented by the many generations of these creatures, the deposit has not grown to sufficient thickness to completely bury the remains.

The data obtained during these explorations has for the first time rendered it possible to lay down on a map of the oceans the distribution of these various deposits. A map of this kind is given in the Challenger Reports, of which Plate VI is a reproduction. The actual extent of these several deposits may be gathered from the following table.

Table showing the Mean Depth and the Estimated Area[*] covered by Marine Deposits on the Floor of the Ocean.

		Mean Depth in Fathoms.	*Area in square miles.*
Littoral Deposits (between tide marks)			62,500
Shallow water deposits (from low water mark to 100 fathoms)			10,000,000
Terrigenous Deposits (in deep and shallow water close to land).	Coral Mud and Sand	740 176	2,556,800
	Volcanic Mud and Sand	1033 243	600,000
	Green Mud and Sand	At varying depths.	850,000
	Red Mud		100,000
	Blue Mud		14,500,000
Pelagic Deposits (in deep water remote from land).	Pteropod Ooze	1044	400,000
	Globigerina Ooze.	1996	49,520,000
	Diatom Ooze	1477	10,880,000
	Radiolarian Ooze.	2894	2,290,000
	Red Clay	2730	51,500,000

Broadly speaking, we see that of the 197,000,000 square miles of which the area of the globe consists, 53,000,000 are land, 144,000,000 sea-bed, of which about 54,000,000 are covered with Red Clay and Radiolarian ooze, about 52,000,000 with calcareous deposits, 10,000,000 with siliceous Diatom ooze, and 27,000,000 with sedimentary deposits, which are being formed round the coast-lines.

As a result of these recent oceanic explorations, certain broad general conclusions may be drawn. With regard to deep-sea deposits, it is clear that they are made up of two groups of materials, (i) pelagic organisms, and (ii) volcanic products; terrigenous material being almost absent. The distribution of the respective deposits is largely determined by the depth, for as we have seen, the calcareous matter decreases as depth increases, and is practically absent at greater depths than 2,800 fathoms, while the deposits resulting from volcanic material are recognised where the calcareous deposits end; in abysmal regions the accumulations which are forming are almost entirely made up of argillaceous matter and siliceous organisms. These deposits are found to be singularly uniform in their composition, and wide in their horizontal extension, and are unquestionably accumulated with extreme slowness. On the other hand, the shallow-water deposits, such as sands and muds, especially those laid down within the 100 fathom line, are of extremely variable composition, and of small horizontal extension, affording every indication that they have been accumulated more rapidly. The comparison of these modern deposits with the stratified rocks which form so large a part of the crust of the earth, shows that the rocks of the crust are allied to the shallower water deposits, and not to the deep-sea deposits; indeed even chalk, which has so many points in common with the Globigerina ooze, presents, as will be shown in a later chapter, many differences in composition and in the nature of the organisms contained in it, and was probably deposited in shallower water than that in which the typical Globigerina ooze is now being laid down in the Atlantic and Pacific Oceans.

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[*] *Report on Deep Sea Deposits, Challenger Expedition*, by Murray and Renard, p. 248.

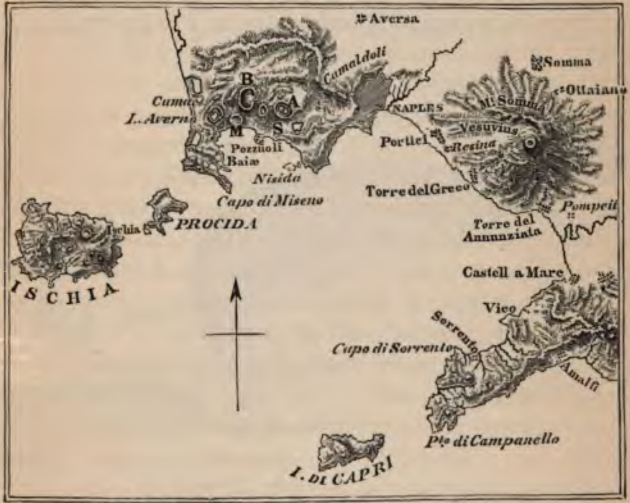
CHAPTER IX.

MOVEMENTS OF THE CRUST.

WE have seen that destruction of the rocks composing the land, and transference of the resulting detrital and dissolved material is ever taking place from higher to lower levels on the earth's surface. We have further seen that the sedimentary material is deposited on the sea-bed to form new strata of aqueous rocks, while the dissolved calcareous salts are, through the intervention of marine life, accumulated as limestones. We have now to consider how the materials laid down in this way on the sea-bed come to be converted into land. This is brought about by movements in the crust, the evidence for which it now becomes necessary to give. Associated with these movements of the crust is a process of another kind by which new rock is formed, and additions made to the surface, namely, by the extrusion of material from the interior to the exterior of the crust, which material, when consolidated, forms beds of Igneous rocks. In considering the question of movements of the crust we shall necessarily have to treat of the phenomena connected with the formation of Igneous rocks.

It will be noted that the two great groups of agencies, to the action of which the earth's crust is subjected (i) the External (which have already been dealt with), (ii) the Internal (which remain to be treated) have corresponding to them the two main classes of rocks, the Aqueous and the Igneous.

The Internal forces manifest themselves in several different sets of phenomena; there are, (1) earthquakes, (2) slow movements of elevation and depression of the crust, (3) volcanoes. These phenomena, diverse as they appear to be, are yet seen on closer study to be intimately connected with one another; they are truly but different manifestations of the action of the same internal forces. It is not necessary for our present purpose to deal with the question of earthquakes, but the upheaval of land, and the ejection of materials from the interior, are both matters needing full treatment. It will be sufficient to point out in passing, that an earthquake is exactly what its name implies—a quaking or tremor of the earth's crust, or as Mr. Mallet has defined it, 'a wave or waves of elastic compression in any direction, from verticality upwards, to horizontality in any azimuth through the crust and surface of the earth, from any centre of impulse, or more than one, which may be attended with sound-waves and sea-waves, depending upon the impulse and upon circumstances of position as to sea and land.' Owing to the fact that earthquakes have frequently accompanied observed elevations of land, the idea that 'land has been upheaved by an earthquake' has taken hold of the popular mind. A consideration of the matter however will show that a mere tremor of the ground cannot be the effective cause of an upheaval, any more than the tremor produced by the firing of an 80-ton gun is the cause of the recoil. The tremor in the gun, the recoil, and the expulsion of the shot are all due to the internal forces set free by the chemical reactions of the ingredients of the gunpowder; so in like manner are the tremor of the ground, the upheaval, and the expulsion of volcanic materials, but different manifestations of the same cause, namely, the interaction of the heated interior and cold exterior of the globe upon one another.



VOLCANIC DISTRICT OF NAPLES

Fig. 18.—MAP OF BAY OF NAPLES.

A Astroni; B Monte Barbaro; M Monte Nuovo; S The Solfatara.

There is abundant evidence establishing the fact, that movements of elevation and depression of the crust occur. It will be interesting to give in detail an account of a well-attested instance within historical times, and no better example can be taken than the well-known case of the Temple of Jupiter Serapis in the volcanic district of the Phlegræan Fields. (Figs. 18 and 19.)

The remains of this ancient building furnish conclusive evidence of oscillations of level to the extent of from twenty to thirty feet since the beginning of the Christian era. The ruins of the temple, situated at Puzzuoli in the Bay of Baiæ a few miles north of Naples, lie on the shore, within a stone's throw of the water's edge. All around are extinct volcanic craters. At a distance of less than a mile is the crater of the Solfatara, which furnishes by its gaseous emanations an example of the latest stage of expiring volcanic activity; about two miles to the

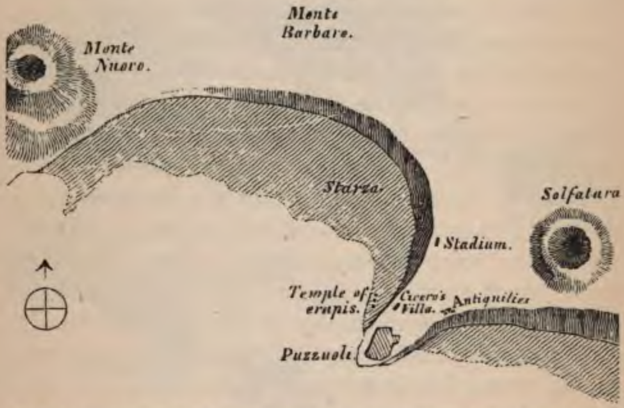


Fig. 19.—GROUNDPLAN OF THE COAST OF THE BAY OF BAIÆ.

north-west is the small but perfect cone of Monte Nuovo; between the two, standing somewhat back, is Monte Barbaro, whose sloping sides terminate within a short distance of the water's edge. In this typical volcanic district in the year 1749 three blocks of stone were discovered in the low-lying ground between the cliff and the sea, protruding from the ground, and nearly concealed by underwood. Excavations were begun in the following year, and the exposed stones were found to be the summits of three marble columns that formed part of the remains of a splendid edifice, believed to have been a temple dedicated to the god Serapis.

The excavations revealed, in addition to the three standing pillars, each carved out of a single block of marble and forty feet three and a half inches in height, a number of broken columns lying on the pavement of the temple, some of granite and some of marble. These were described in detail by Mr. Babbage in a paper to the Geological Society, from notes made when he visited the temple in 1828[1]. The ruins have been carefully preserved and their characteristic features may still be studied on the spot.

From the base of the standing pillars up to a height of nine feet the marble is uninjured. At this point, however, a calcareous coating occurs which covers the column for about one foot of its height; then follows a space of one foot five inches, which is uncovered and uninjured. Above this uninjured portion the column is closely pitted with cavities made by boring molluscs, at the bottom of many of which shells were still to be found when Mr. Babbage made his observations; but as the cavities were pear-shaped, it was difficult to extract perfect specimens. The length of column perforated in this way was found by Mr. Babbage to be eight feet two and a half inches, and he noted near the top of the perforated portion a slight indentation right round the columns, which seems to indicate by the corrosion on that spot, that it remained for a considerable time the line of the level of the water. These features are well shown in the reproduction of the photograph (Fig. 20). On the right, close to the margin

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[1] *Observations of the Temple of Serapis*, by C. BABBAGE. *Quart. Jour. Geol. Soc.* vol. iii. p. 186.

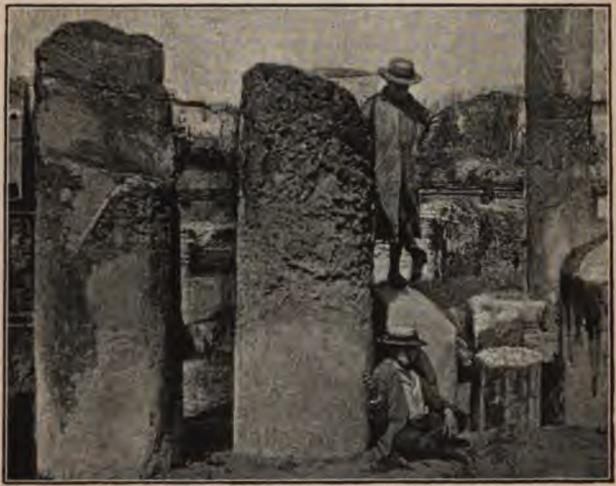

Fig. 20.—RUINS OF THE TEMPLE OF JUPITER SERAPIS, WITH PORTIONS OF PERFORATED COLUMNS IN THE FOREGROUND.
(From a photograph by the Author.)

of the picture, one of the standing columns is seen displaying clearly the corroded band above referred to. Fragments of other marble columns were found lying on the floor of the temple presenting perforations similar to those in the standing pillars, not only on the exterior, but also on the cross-fracture, and to some of them Serpulæ and other marine forms had attached themselves, affording additional proof of the marine conditions to which the ruins had been exposed. The foreground of the illustration is occupied by a portion of one of these fragments in which the borings are admirably shown.

The presence of these borings proves beyond question that the pillars must have been immersed in sea-water for a considerable period, and as they are confined to a band that begins at a height of about eleven feet, it is obvious that the lower parts of the column must have been covered up and protected when this immersion took place. The platform of the temple was, when Mr. Babbage visited it, and is still, below high-water mark, while underneath the existing platform, at a depth of about five feet, another, richly ornamented, was discovered. This seems to imply an earlier subsidence which had rendered it necessary to construct a new floor at a higher level.

We now proceed to consider at what date the oscillations took place, the records of which are preserved to us in the perforated columns. The temple was probably constructed in the second century, for inscriptions within the building prove that its walls were adorned with precious marbles in the years 194 A.D. and 211 A.D., and that a further adornment took place between the years

222 A.D. and 235 A.D. From that time down to the uncovering of the ruins in the middle of the eighteenth century, very little is known of the history of Puzzuoli. Fortunately, however, the successive deposits that enveloped the columns were themselves a series of most interesting natural records, throwing light upon the events of those centuries. The nature of the succession will be seen in Fig. 21. On the internal walls of the temple a dark brown incrustation was noted consisting in the main of carbonate of lime which must have been deposited from water. The well-defined dark horizontal lines which occur at different heights on this incrustation render it clear that the sinking of the pavement was gradual, with intervals of repose. It also seems certain from the presence of Serpulæ on the incrustation, that the sea entered in and mingled its waters with those of the hot springs which rise in the Temple, and from these mixed waters the calcareous incrustation was thrown down.

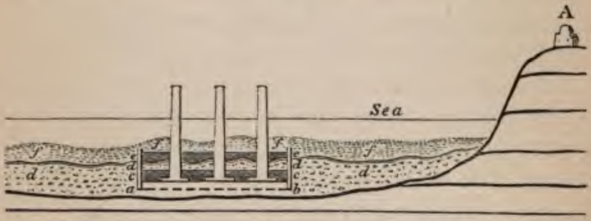

Fig. 21.—SECTION ILLUSTRATING THE CONDITION OF THE TEMPLE OF JUPITER SERAPIS AT ITS PERIOD OF GREATEST DEPRESSION.

A Stadium. *a b* Ancient Mosaic pavement. *c c* Dark marine incrustation. *d d* First deposit of volcanic ashes. *e e* Fresh-water calcareous deposit. *f f* Second deposit of volcanic ashes.

Then came a deposition of volcanic tuff, which it is conjectured was thrown out from the Solfatara when that volcano was in a former stage of more vigorous activity. Over this another calcareous deposit was laid down, which was succeeded by an irregular mass of volcanic ashes, making a thickness of ten or eleven feet above the pavement, thus covering the pillars up to the height at which the perforations begin. The next event in the history of the temple must have been a rapid and considerable depression, bringing the surface of this deposit nine feet below the sea-level, and leaving a band of between eight and nine feet exposed to the action of the boring molluscs, while the upper half (about twenty feet) of the columns was exposed to the atmosphere. How long this state of things lasted we can only conjecture, but eventually other strata, consisting of volcanic materials and rubbish washed in during storms, covered up the temple to a height of about thirty-five feet above the pavement, and in that condition it was found when the excavations were made in 1750. Observations recorded in the early part of the present century prove that a gradual subsidence was at that time taking place, and it was estimated that in less than fifty years the temple had subsided more than two feet.

Here we have incontrovertible evidence of movements of depression and subsequent elevation of the land of at least twenty feet, which took place between 235 A. D., when the temple was freshly adorned with marbles and presumably therefore was intact, and 1750, when the excavations were made which disclosed the ruins. We are fortunately able further to fix a date before which the depression must have reached its maximum, for certain deeds of the early part of the sixteenth century refer to tracts of land where the *sea was drying up, or was dried up*, in other words where the land was undergoing elevation. One of these deeds, dated October 1503, relates to a grant of land to the University of Puzzuoli, the other is dated about eight years later. There can be little doubt that the elevation which had clearly begun at that time became more marked and rapid during the formation of the volcanic cone of Monte Nuovo in 1538, for eye-witnesses of that event refer to the fact that the sea retreated from a considerable extent of shore. One of the observers states that the inhabitants of Puzzuoli during the eruption fled towards Naples, carrying fish which they had found on the shore, the sea having abandoned a large tract. Another account states that during the eruptions, 'the sea immediately adjoining the plain dried up about 200 paces, so that the fish were left on the sand a prey to the inhabitants of Puzzuoli.' This testimony leaves no room for doubt that a considerable elevation of the land (for that is clearly what the retreating of the sea means) took place during this manifestation of volcanic activity in the Phlegræan Fields.

Attention has recently been drawn[2] to an interesting passage in an ancient document which seems to afford fair ground for fixing still more definitely the date of the period of greatest depression. We have seen that the temple was certainly above water in the third century, when it was adorned with marbles by the Emperor Severus, and certainly submerged in the early part of the sixteenth century, when the documents above quoted prove that the land was rising. At what period during these thirteen centuries did the great submergence take place? In the *Acta Petri et Pauli*, believed to date from the fifth century, the following passage occurs:—

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[2] *Geol. Mag.* June 1892, p. 282.

'And Paul being in Ponteole (Puzzuoli), and having heard that Dioscorus had been beheaded, being grieved with great grief, gazing into the height of heaven, said, 'Oh, Lord Almighty, ... punish this city and bring out all who have believed in God and followed His word.' He said to them therefore, 'Follow me.' And going forth from Pontiole . . . . they came to a place called Baias (Baiæ), and looking up with their eyes they all see that city Pontiole sunk into the sea-shore about one fathom; and there it is until this day for a remembrance under the sea[3].' It is evident from the concluding words that when the *Acta* was written, Puzzuoli was under water, and had been so for so long a time that the memory of the actual events had been lost and replaced by the tradition recorded in the *Acta*. The subsidence must therefore have occurred between the third and fifth centuries, and probably earlier than the fourth. This would allow about ten centuries during which the marble columns of the temple were under water exposed to the action of the boring molluscs.

It is of interest to note that the whole coast of that part of Italy furnishes evidence of elevation. Marks, such as might have been worn by the waves, have been observed on the inland cliffs, at a considerable height above the present sea-level, and the remains of barnacles have been found attached to the face of the rock, which also exhibited borings by marine shell-fish. Dr. Johnston-Lavis has recently drawn attention to very interesting evidence of elevation in the Ponza Islands off the Italian coast[4]. He states that the Island of Palmarola, the largest of the group, is divided by a depression, somewhat in the form of an amphitheatre, open to the west, and shelving down to the beach. The lowest part of this depression is strewn with boulders, covered with Serpulæ and other marine growths looking quite fresh, but above sea-level. Dolomieu, who visited the Ponza Islands in March, 1786, describes Palmarola as being divided into two nearly equal parts *by a narrow canal, along which a barge might pass*; and he gave in his paper a map of the Islands, showing the canal in the position of the amphitheatre depression, which is now at a considerable height above high-water mark. This affords evidence of the most conclusive kind of a change of level in Palmarola, which Dr. Lavis believes to be about 200 feet. His investigations were unfortunately cut short by a curious circumstance before they were completed. 'Cholera,' says Dr. Lavis, 'was then raging at Campobasso on the mainland, and the islanders not comprehending the curious habits of a travelling geologist, supposed I had been sent by the Government to spread the "Cholera-powder," and requested me to leave the island by the next steamer.'

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[3] *Ante-Nicene Christian Library*, vol. xvi (Acts of the Holy Apostles, Peter and Paul), p. 258.

In other parts of the Mediterranean similar evidences of recent elevations occur, such as the upraised strata containing marine-shells with fragments of antique pottery at Cagliari on the southern coast of Sardinia, which have been elevated to a height of 230 to 324 feet above the present level of the Mediterranean.

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[4] *Geol. Mag.* Decade III, vol. vi (1889), p. 535.

In addition to evidence of movements in historical times there is much to show that similar movements of elevation and depression were constantly taking place in the crust of the earth in pre-historic times. On various parts of the coast of Great Britain, raised beaches occur marking a former position of the sea at high-water, and indicating an elevation of the land, while in other parts submerged forests offer equally conclusive indications of depression.

Confirmatory evidence of a very interesting character of movements in the past is furnished by the study of the geographical distribution of animals and plants. To demonstrate the full force of this evidence it would be necessary to enter into a detailed account of the general features of the distribution of living forms over the earth's surface. This is outside the scope of this volume; but as the matter is of much interest, it may be worth while to indicate briefly the nature of the argument.

If two countries now separated by sea exhibit strong points of resemblance in their animal and plant life, there is fair presumption that they were formerly connected with one another. For example, the forms of life inhabiting Africa north of the Sahara present a close alliance with European forms. The fauna and flora of South Africa are entirely different from those of North Africa, the desert of Sahara with its arid sands making a barrier which neither the European forms inhabiting the

North, nor the characteristic forms of the South, with the exception of a few desert haunters, are able to cross. Of the Algerian species of mammalia, fifty-seven are European, while only seven or eight are South African, and these are, as a rule, forms that have a wide range, like the lion, leopard, cerval, and a species of antelope, to which the desert offers no barrier. On the other hand, some species that occur in South Europe, the Gibraltar monkey, for instance, are characteristic North African forms. This indicates unmistakably that Europe and North Africa were at some former period connected by land, over which the migration of animals and plants could freely take place, from one country to the other. That there was this connection is independently suggested by the existence of the three submarine ridges stretching across the Mediterranean sea-bed, one from Gibraltar to Cape Spartel, another in the line of Corsica and Sardinia, and a third from Sicily to Tunis. Along these lines the sea is so shallow, that an elevation of a few hundred feet would connect the two countries by isthmuses, and the Mediterranean sea would be converted into three or four great lakes. Some curious evidence confirming the view that the land connection was by these ridges is derived from the study of the migration of birds. It is known that birds which migrate into the African continent for the winter, cross the Mediterranean at certain fixed points only[5]. These points are (1) Straits of Gibraltar; (2) from the Gulf of Genoa, by Corsica and Sardinia to Tunis; (3) from Italy, by Sicily and Malta to Tripoli;

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[5] *Contemporary Review,* vol. xxxiv. (1879), p. 531. ('The Migration of Birds,' by Dr. August Weissmann.)

(4) from Asia Minor, by Cyprus to Egypt. It does not appear that these points are chosen because they are in every case the shortest, for a more direct route than from Tripoli to Malta would be from Cape Bon to the western point of Sicily. Why then do birds take this particular course? By assuming that the migration began at a time when North Africa was connected with Europe at the points referred to, and that a slow and gradual subsidence of the land was taking place, which finally led to a complete severance of the land connection, the explanation is clear. The birds naturally migrated along the isthmuses which soundings show did not always lie in the most direct line from one continent to the other. At first they passed over a broad and then gradually narrowing belt of land, later still over marshes and lagoons, then over a small arm of the sea, and finally over broad waters, and yet no single generation may have been aware of any change. The land, so to speak, was gradually withdrawn from beneath them and imperceptibly their flight over connecting belts of land was changed into a passage across the sea. Thus, while the subsidence was going on the migratory birds continued year after year to take the same course according to the fixed habit formed by generations of repetition, so that after the connecting land-ridges had entirely disappeared, the birds still clung to the same old lines of passage, and continue to follow them to the present day.

Sufficient evidence has now been adduced to prove that movements of elevation and depression occur in the crust of the earth. Apart, however, from all this, the aqueous or sedimentary rocks show by their structure and by the entombment in them of the remains of marine forms of life, that they must have been originally deposited on a sea-bed. The present position of these rocks, which constitute so large a part of all land-areas and are found in hilly and mountainous regions thousands of feet above sea-level, implies movements of the crust on the grandest scale, often repeated in the revolution of geological time.

CHAPTER X.

VOLCANIC ACTION.

Explosive Eruptions.

THE subterranean forces, whose slow and quiet action in the way of elevation and depression of the crust we have been considering, also manifest themselves in more violent outbursts, which are accompanied by an actual transference of material from the interior to the exterior of the crust. These may take the form of (1) *Volcanic eruptions*—outbreaks at one spot, with the violent expulsion of dust, scoriæ, and possibly lava; or (2) *Fissure eruptions*—more quiet welling up or overflowing of lava from a line of fissure.

A volcano has been defined as 'a more or less conical mass, having at its summit a basin-shaped hollow, the crater, which communicates below with a fissure in the earth's crust, through which steam and other gases, lava, hardened scoriæ and fragments of triturated rock, known as volcanic ash and dust, are ejected.' Thus a volcano is fundamentally an opening in the crust, through which the pent up internal forces find relief by the expulsion of materials from the interior, the cone itself being nothing but a huge mound of volcanic ejectmenta, accumulated around the orifice. (Fig. 22.) Some of the older geologists, notably Von Buch, de Beaumont, Humbolt, and Davy held the view that volcanic mountains were due to upheavals of the crust, that in fact the ground, under the action of the internal forces, was upraised into a great bubble, which fissuring at its summit gave vent to gases, fragmentary materials, and molten lava. Careful and detailed study of the structure of volcanic cones has proved conclusively that the 'elevation' theory, in the crude form put forward by the old geologists, is untenable, and that the cones are built up of the materials ejected from the crater. The history of the formation of Monte Nuovo afforded ocular demonstration of this.

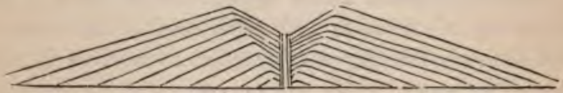

Fig. 22.—DIAGRAMMATIC SECTION OF A VOLCANIC CONE SHOWING ARRANGEMENT OF EJECTED MATERIALS.

This small volcano, situated on the Italian coast near Puzzuoli, came into existence in the year 1538. The cone is 440 feet high, with a circumference round the base of a mile and a half, while the depth of the crater is 421 feet. It stands on a site which, up to September 29, 1538, was partly covered by the Lucrine Lake. The whole process of its formation during an eruption in that year was observed and described by eye-witnesses. The neighbourhood for two or three days previous to the eruption had been disturbed by frequent earthquakes. On Sept. 29, about one o'clock in the morning, a fissure appeared on the spot where Monte Nuovo now stands, through which ashes and pumice-stone, mixed with water, were thrown out in great quantity. The mud was described as at first very liquid, and then by degrees less so. The materials ejected were in such quantity, that in less than twelve hours a hill 100 paces in height was formed. This action was continued at intervals for about a week, until the cone reached the dimensions it now possesses. Some of the supporters of the elevation theory claimed that the cone of Monte Nuovo was due not to the accumulation of erupted materials but to the upheaval of solid beds of upraised tuff. The weight of evidence is however entirely against this theory, for all the eye-witnesses describe the ejection of material and its accumulation round the vent to form the cone, so that there can be no question that the volcano as we now see it is nothing more than a great mound of volcanic ejectamenta. The eye-witnesses however do speak of an actual uprising of the ground to the extent of a few feet, which preceded the volcanic outbreak, but that this was only very slight is proved by the fact that the walls of the Temple of Apollo at the foot of the hill maintained their perpendicularity. This could not have happened if the cone had been the result of upheaval. The following extract is from the vivid and picturesque account of the eruption given in a letter from Francesco del Nero to Niccolo del Benino, written in 1538, and found in a volume in the Library of the Marquis Capponi, a translation of which has been published[1].

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[1] *Quart. Jour. of the Geol. Soc.* vol. iii. (1847).

'On the 28th of September, at midday, the sea-bottom near Puzzuoli became dry over an extent of 600 braccie (1300 yards) so that the inhabitants of the town carried off wagon-loads of fish left on the dry land. About eight o'clock in the morning of the 29th, the earth sank down about two canne (13½ feet) in that part where there is now the volcanic orifice, and there issued forth a small stream of very cold water, as we were told by some persons we interrogated, but others stated it was tepid and somewhat sulphureous: as all the people whom we spoke to were persons worthy of credit, I am of opinion that they all spoke the truth, and that the water was at first cold and then tepid. At noon on the same day, the earth begun to swell up, so that the ground in the same place where it had sunk down 13½ feet by eight o'clock, or thereabouts, was as high as Monte Ruosi, that is, it was as high as that hill is where the little tower stands upon it; and about this time fire issued forth and formed the great gulf with such a force, noise, and shining light, that I, who was standing in my garden, was seized with great terror. Forty minutes afterwards, although unwell, I got upon a neighbouring height from which I saw all that took place. And by my troth, it was a splendid fire, that threw up for a long time much earth and many stones. They fell back again all round the gulf, so that towards the sea they formed a heap in the form of a cross bow, the bow being a mile and a half, the arrow two-thirds of a mile in dimension. Towards Puzzuoli, it has formed a hill nearly of the height of Monte Morello, and for a distance of seventy miles round, the earth and the trees are covered with ashes.

On my own estate I have neither a leaf on the trees nor a blade of grass; in the neighbourhood of Puzzuoli, to a distance of six miles, there is not a tree standing which has not had its branches broken, and frequently it is not possible to say that there has been a tree on the spot. The ashes that fell here were soft, sulphurous, and heavy. They not only threw down trees, but an immense number of birds, hares and smaller animals were killed.'

There seems little doubt from this testimony that a true movement of upheaval did take place in the district during the eruption of Monte Nuovo, but the evidence is overwhelming against the theory that the volcanic cone itself was the result of any such swelling of the ground as Von Buch and those who held similar views supposed.

It will be advantageous at this point to draw attention to certain important facts relating to volcanic action. The majority of volcanoes on the earth's surface are intermittent in their action; periods of activity being followed by periods of repose. The intervals between successive eruptions may vary to almost any extent, from a few minutes, as in the case of Stromboli, which furnishes an example of a volcano in a constant state of gentle eruption, to hundreds of years, as was the case with Vesuvius in the middle ages.

At the end of the chapter a table is given showing the successive eruptions of Vesuvius from 79 A.D. to the present time. From this table it will be seen that there is no definite law governing the length of intervals between successive eruptions; but the study of the volcanic history of the whole district, from Ischia to Naples, brings out very clearly a most interesting circumstance. The Map (Fig. 18) shows that the volcanoes—extinct and active—lie on a curved line from Ischia around the Bay to Vesuvius. There is every probability that this is a line of fissure in the earth's crust, and it seems likely that the Lipari Islands are a centre, from whence lines of fissure radiate northwards and southwards, along which the volcanic manifestations of Italy and Sicily have occurred. A comparison of the dates of eruptions of the volcanoes in this district brings out the important point that the focus of activity has shifted from time to time along the line, the volcanic outbursts never occurring over the whole area at one and the same time. Before the Christian era, Ischia, at the north-west end, was the scene of activity. Terrific earthquakes and eruptions succeeded one another with such violence and rapidity that at last the Greek colonies were compelled to retreat. By the beginning of the Christian era, however, a period of repose had set in. At that time Vesuvius was and had been from time immemorial entirely quiescent, and no historic record existed of any eruption before 79 A.D., when the transference of the centre of activity took place from the northern to the southern end of the district. Since that time, for 1800 years, only one eruption, that of 1302, has been known in Ischia, when a stream of lava was emitted from Monte Epomeo without the explosive violence that characterised the eruptions in pre-Christian times. When this eruption took place it is important to note that Vesuvius was in the middle of a long period of quiescence, so that it marked a temporary transference of the centre of activity again to the north.

Thus between 1139 and 1631, a period of about 500 years, Vesuvius enjoyed tranquillity, with the exception of one unimportant eruption in 1306. Following that period and preceding it eruptions of Vesuvius were frequent. During the time when Vesuvius was dormant, not only did the eruption, already referred to, in Ischia occur, but there was an eruption of the Solfatara in 1198, and the remarkable outburst of activity in 1538 near Puzzuoli which resulted in the formation of Monte Nuovo.

It will be seen that the table of eruptions (Table I), besides emphasizing this point, brings out another of much interest, namely the connection between slow movements of elevation and depression and volcanic manifestation. When Ischia and the Phlegræan Fields were the centre of volcanic activity and Vesuvius was quiescent, the Temple of Jupiter Serapis stood high. On the other hand, between the third and the twelfth centuries, when the Ischian volcanoes were quiescent and Vesuvius was in eruption, the depression proved by the borings in the pillars occurred, while between the twelfth and sixteenth centuries, when the centre of activity had shifted again to Ischia and the Phlegræan Fields, the land was rising. Thus we see that local elevation was associated with volcanic activity in the district, and depression with quiescence. This is of course exactly what might have been expected, for volcanic activity implies the existence of subterranean energy seeking vent. It is important, however, to note that recent researches into the volcanic manifestations of past times point to the conclusion that long-continued volcanic action on a grand scale is a feature of sinking areas. This general subsidence is in no way inconsistent with some measure of local-elevation at the centre of activity.

We now proceed to consider the nature of the ejectamenta of which volcanic cones are built up. They may be classified under two heads, (1) fragmentary materials, consisting of volcanic dust, scoriæ, and ashes, and (2) lava. At the first outbreak of volcanic action, as might have been expected, it is fragmentary materials, as a rule, which are thrown out. This was so in the case of the eruption of Vesuvius in 79 A.D. No previous eruption of that volcano in historic times had been known. The ancient crater with its steep cliffs was overgrown with wild vines; the mountain slopes were covered with fertile fields, richly cultivated, and at its base were the populous cities of Herculaneum and Pompeii. The first indication of an outburst was an earthquake in 63 A.D., and from that time until 79 A.D. these indications increased in frequency and violence, and finally culminated in an eruption, a full description of which has been handed down to us in Pliny's letters.

From the summit of the cone a dense column of vapour was seen rising vertically and then spreading out laterally, so that its upper part resembled the head, and its lower part the trunk of an Italian pine. Volcanic ashes and dust were ejected in great quantity, and the immense volumes of steam which were given out condensed and fell in torrential rains, carrying down with them ejected ashes and dust, forming streams of mud, which with volcanic materials that fell directly, overwhelmed and buried Herculaneum and Pompeii. It was not until the seventh eruption in 1036 that there was any outflow of lava from Vesuvius, all the ejectamenta in previous eruptions having consisted of fragmentary materials. The term *ashes* as applied to these volcanic materials is an unfortunate one, for it suggests products of the partial combustion of coal, or other material containing inflammable gases. *Volcanic ashes*, however, are not in the slightest degree of this character. They are portions of partially fused rock rendered roughly vesicular by the gases disengaged from them. The larger rough cindery-looking fragments are described as *scoriæ*. When the vesicles are filled with mineral matter separating from the mass or infiltered by water permeating the rock, it is called an *Amygdaloid* (Fig. 23), the name being derived from the almond shape often assumed by the vesicles and their contents. The finest material of all, which results from the trituration of fragments thrown up during eruptions, and from the explosive disengage-

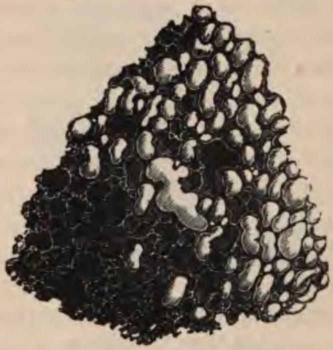

Fig. 23.—SCORIACEOUS LAVA IN PART CONVERTED INTO AN AMYGDALOID.

ment of steam from the scoriaceous surface of the lava in the crater, is described as *volcanic dust.* The term *tuff* is applied to the beds of fine scoriæ, pumice, and dust that are formed where these materials are showered down as the result of volcanic explosions (Fig. 24); while accumulations of angular fragments of ejected blocks cemented together, are described as *volcanic agglomerates.* These ejectamenta are distributed far and wide during great eruptions, and afford striking indications of the stupendous energy of the subterranean forces.

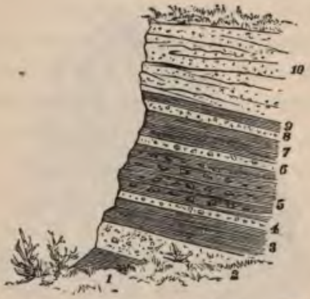

Fig. 24.—INTERSTRATIFIED VOLCANIC TUFF AND SHALE from Lower Carboniferous.
(After Geikie.)

1, 3, 5, 7, 9, Shales; 2, 4, 6, 8, Bands of Volcanic Tuff; 10, Coarse Agglomerate Tuff.

Mr. Whymper has described a very impressive instance of this during the eruption of Cotopaxi, which he witnessed while ascending Chimborazo 60 miles distant[2].

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[2] *Travels amongst the Great Andes*, by EDWARD WHYMPER, pp. 322–329. Murray.

He states that just before daylight a column like smoke commenced to rise from the crater, going straight up into the air with a velocity so great that within a minute it had risen 20,000 feet above the crater. It was carried by the wind towards Chimborazo, until it got overhead about noon and shut out the sun. Through rifts in the clouds the ascending column of ash, blacker than the blackest ink, was seen rising to an immense height in the air. This descended on Chimborazo in such quantity that the snow looked like a ploughed field. At the town of Ambato, twenty miles nearer the mountain, four ounces of dust were collected on a sheet of paper one foot square in fifteen minutes. From these data Mr. Whymper calculated that at least two million tons of ash were ejected during the eruption. When examined microscopically the particles were found to consist chiefly of glassy felspar, and fine long crystalline scoriaceous dust. The ash which fell on Cotopaxi itself, close to the crater, was so fine that 4000 particles scarcely weighed a grain, while that which fell on Chimborazo was far finer, a grain including at least 25,000 particles. Reflecting on this we gain some conception of the enormous force required to eject two million tons of this excessively fine dust to a height of four miles above the crater, unaffected by the wind!

Another instance of tremendous explosive action, and consequent wide diffusion of volcanic dust, was the great eruption of Krakatoa in 1883. Krakatoa is a small island in the Sunda Strait between Sumatra and Java, situated at the crossing of two lines of volcanic activity pointing, there is little doubt, to the intersection of two great fissures in the earth's crust, along which volcanic manifestations have taken place. There is no part of the world where subterranean energy is more active than in this district. The island of Java, equal in area to England, possesses no fewer than forty-nine volcanoes, some rising to a height of 12,000 feet above sea-level, and most of them have been in eruption since the European occupation of the island. For two centuries preceding 1883, the volcanoes of Krakatoa had been dormant, but since 1876 the region had been frequently troubled by earthquakes, giving token that the volcanic forces were awakening to fresh activity. On the morning of May 21, 1883, the eruptions began with an ejection of volcanic ashes, and during the succeeding days a dome-shaped mass of vapour was seen to rise from the island. Loud explosions occurred, accompanied by a fall of dust and pumice upon the island and beyond its limits. The violence of the eruptions increased, and on May 26 observers noted that the column of vapour rose to a height, it was estimated, of about 10,000 feet, while fragments of pumice were shot up to a height of 600 feet. Great quantities of dust and ashes continued to be ejected, until the forests of Krakatoa were completely destroyed, only a few trunks of trees being left standing above the thick covering of pumice and dust. Finally the action culminated in the tremendous explosion of August 27.

Much interesting testimony as to the phenomena attending the eruption has been collected from the logs of ships in the neighbourhood, and from the reports of observers in different parts[3]. It appears that during this final outburst, columns of dust were projected into the air to an immense height, which was estimated by various observers, at from 12½ miles to 23 miles. This mass of vapour and dust was seen by the captain of a ship then sailing at a point 76 miles E.N.E. of Krakatoa, who described it as 'a black mass, rising up like smoke in clouds' to a height estimated at 17 miles. The captain of another ship nearer to the island, describes it as presenting 'the appearance of an immense pine-tree, with the stem and branches formed with volcanic lightning'; the air was loaded with excessively fine ashes, and the captain describes his ship as passing 'through a rain of ashes and small bits of stone.' When the dust-fall began, a dense darkness overspread the country to a distance of 150 miles from the volcano. Three vessels were all day beating about in the darkness at the eastern entrance to the strait, with pumice dust falling about them in quantities so great as to employ the crews for hours in shovelling it from the decks, and in beating it from the sails and rigging. On another ship at anchor to the north, pumice and dust fell mixed with water in the form of mud, and accumulated on the deck, at the rate of six inches in ten minutes.

The rich colouring of the sky shortly before and after sunset, and other remarkable atmospheric phenomena witnessed in so many parts of the world after the Krakatoa eruption, have been attributed to the effect upon light of the finely divided dust projected into the higher regions of the atmosphere during the outburst.

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[3] *The Eruption of Krakatoa.* Report of the Committee of the Royal Society. Trübner & Co.

In the Report on the eruption already referred to, Professor Judd records the results of his examination of a large number of samples of the Krakatoa dust collected at many places, ranging from 40 to 1000 English miles away from the volcano. He states that there are no data for forming any trustworthy estimate of the quantity of dust thrown into the air during these outbursts; but he points out that the continuance for more than three months of the work of trituration among the masses of pumice of so particularly brittle a character as that ejected from Krakatoa, must have given rise to vast quantities of fine particles, which would be gradually diffused into the higher regions of the atmosphere.

What the total amount of material may be thus spread over the surface of the globe as the result of explosive volcanic action it is impossible to estimate, but that it is enormous there can be no doubt. In a former chapter the wide diffusion of volcanic products over the sea-bed revealed by recent deep-sea explorations was noted. The Red Clay which Dr. Murray has shown to be in the main the result of the decomposition of pumice and other volcanic materials, covers 51 million square miles, no less than one-fourth of the whole area of the globe—an extent of surface equal to that of all the land areas.

TABLE I.

Relation of Eruptions in the Italian Volcanic District to movements of Elevation and Depression.

ISCHIA AND THE PHLEGRÆAN FIELDS.	TEMPLE OF JUPITER SERAPIS.	A.D.	VESUVIUS.
Before Christian Era. Terrific eruptions in Ischia.	Temple in existence long before Christian era, but probably reconstructed before end of second century when adornment with precious marbles took place. A slight previous sinking had certainly occurred.		*Quiescent.*
1st century to 1139. *Ischian volcanoes quiescent.*	TEMPLE SUNK.	79 203 472 542 685	Eruptions separated by considerable intervals.
		993 1036 1048 1138–9	Eruptions more frequent.
1198. Eruption of the Solfatara in the Phlegræan Fields.	TEMPLE PROBABLY RISING.		*Quiescent for* 168 *years.*
1302. Eruption of Monte Epomeo in Ischia.		1306	Eruption.
			Quiescent for 194 *years.*
1538. Eruption of Monte Nuovo in the Phlegræan Fields.	TEMPLE CERTAINLY RISING.	1500	Slight Eruption.
			Quiescent for 131 *years.*
1538 to 1892 *Volcanoes of Ischia and Phlegræan Fields quiescent.*	TEMPLE SINKING.	1631 to 1892	Vesuvius in frequent eruption at intervals of rarely more than four or five years.

CHAPTER XI.

VOLCANIC ACTION.

Extrusion of Lava.

As already stated, the ejection of fragmentary materials is usually accompanied or followed by an outflow of molten material—lava—which solidifies on cooling and forms igneous rocks. It is seldom in a state of perfect fusion, although instances are known of lava streams flowing with the rapidity of rivers, filling channels in their course, and deluging the country as a flood of water might do. The lava usually consists of a mass of small crystals, and other solid particles, enveloped in a pasty semi-fluid matrix, permeated throughout with super-heated steam and other gases. The presence of these vapours is demonstrated not only by the fact of their emission during eruptions, but by the minute cavities filled with water, which are revealed on microscopical examination in the cooled and consolidated lava.

On issuing from the vent the molten stream cools rapidly, its surface becoming covered with a scoriaceous crust due to the bubbling up of steam and other gases, just as bread becomes vesicular under the action of fermenting yeast. This is soon broken up by the motion of the mass, which generally presents the appearance of a huge mound of cinders, slowly moving along. The scoriaceous crust, formed in this way, checks the escape of heat, so that the interior of a lava sheet, having cooled more slowly, presents a more compact and crystalline character than the rapidly-chilled exterior. When the lava, instead of pouring out at the surface, is forced up into fissures in the superincumbent rock and there solidifies, forming dykes, the vesicular, scoriaceous surfaces, so characteristic of the sheets that have flowed from a volcanic vent, are absent. The pressure of both sides upon the molten mass filling the dyke, and the slow cooling, prevent the escape of gases that would give the vesicular character, and thus the whole rock becomes more compact and crystalline.

Attention has already been drawn to the fact that the fluidity of lava varies considerably, some varieties displaying a very perfect degree of liquidity, others being much more tenacious and viscous. It is a noteworthy circumstance that lavas poured out during different eruptions from the same volcanic vent, and having substantially the same chemical composition, display this difference in degree of fluidity. Examples of the two extremes may be observed in modern Vesuvian lavas. Mr. Scrope describes the flow of lava witnessed by himself in October, 1822, which was so fluid and moved so rapidly that it descended the entire slope of Vesuvius in fifteen minutes[1]. Other lava flows have 'dribbled languidly down its steep sides and stiffened there without reaching its base at all, just as a run of wax or tallow in a "guttering" candle hardens on the outside of the upright shaft.' These variations in the rate of flow are associated with differences in the character of the cooled surface of the lava. The slow-moving flows present a curious twisted appearance of the surface, resembling coils of rope, due to the wrinkling up of the chilled crust by the movements of the liquid material below. This characteristic feature is well displayed in the lava current of 1858. The surface of a rapidly flowing lava stream, on the other hand, like that of 1872, is in marked contrast to that just described. It presents a rough cindery appearance, and consists of masses, irregular in shape and often of large size, whose rough and jagged angles make it extremely difficult to traverse.

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[1] *Volcanoes*, by G. Poulett Scrope, F.R.S., p. 68.

While these surface characters cannot be entirely due to variations in the composition of the lavas, seeing that those erupted from Vesuvius, to which reference has been made, present great similarity in composition, it is certain that chemical composition is generally an important factor in determining fusibility and degree of liquidity. Without entering here into a detailed discussion of the chemical and mineralogical constituents of lavas, it will be advantageous to point out the broad distinction in composition between the two main classes of igneous rocks. Of the sixty or seventy elementary substances detected by chemical analysis in the rocks of the crust of the earth, only a few are present in large quantity. The bulk of rocks consist of the following elements, in various combinations, forming different minerals: oxygen, silicon, aluminium, magnesium, calcium, iron, sodium, and potassium. Of these, oxygen is by far the most abundant, and makes up nearly one half the whole weight of the earth. In combination with silicon, it forms silica, or silicic acid, which, in its pure mineral form occurs as quartz, or rock crystal. Silica, like other acids, has the power of combining with bases, such as the oxides of the elements above named, to form silicates of which igneous rocks and the minerals occurring in them are composed. If fused silicates are allowed to cool slowly, they tend to assume a crystalline condition; the whole exhibiting when cold the appearance of a felted mass of crystals of one or more minerals. The slower the cooling the more coarsely crystalline is the mass likely to be, while the more rapidly it is cooled, the more nearly it approaches the amorphous or glassy non-crystalline condition. Broadly speaking igneous rocks are divisible into two principal groups according to the proportion of silica—the acid constituent—which they contain. Those in which silica is present in the proportion of from 60 to 80 per cent., are classed as *Acid rocks*, while those containing only 45 to 50 are known as *Basic rocks*. These classes may be conveniently subdivided in the way shown in the following table.

Subdivision according to Chemical Composition.	*Volcanic.*	*Plutonic.*
Acid (75 to 77 p.c. Silica)	Rhyolites	e. g. Granite.
Sub-Acid (62 to 64 p.c. Silica)	Trachytes	
Sub-Basic (55 to 60 p.c Silica)	Andesites	e. g. Gabbro.
Basic (45 to 50 p.c. Silica)	Basalts	

It will be seen from the above that, as in all other departments of nature, there is no sharp line of demarcation between these two groups—Acid and Basic—for every intermediate stage occurs between extremely basic rocks, like some of the Basalts, in which the percentage of silica is 45, and highly acid rocks like the Rhyolites which contain 77 per cent. of silica.

The truest way to regard these igneous rocks is, undoubtedly, as forming a series, passing by insensible gradations from the one extreme to the other, and not as sharply separated into distinct groups.

The Acid rocks in addition to containing a large percentage of silica are rich in potassium and sodium, and poor in the oxides of calcium, magnesium, and iron, while as a rule they are light in colour. Basic lavas, on the other hand, are rich in the oxides of calcium, magnesium, and iron, poor in potassium and sodium, and usually dark in colour. They also are the more fusible, acquire the most complete liquidity, and crystallize the most readily, while Acid lavas are not so easily fused, display considerable viscosity, and tend in cooling, if it is rapid, to assume a glassy instead of a crystalline structure.

In the foregoing table it will be noted that a twofold classification is given: the one according to chemical composition into *Acid* and *Basic*, the other according to mode of origin into *Volcanic* and *Plutonic*. Under the head of Volcanic rocks are included all those which have been a direct result of volcanic action, have reached the surface like modern tuffs, agglomerates, and lavas, and have cooled comparatively quickly; they are usually finely crystalline or glassy in structure. The Plutonic rocks are those which have been formed at a depth below the surface under great pressure, and have cooled slowly; they are always crystalline, and usually coarsely so. They appear at the surface as the result of the removal by denudation of the superincumbent rocks, into which they were originally intruded.

After this short digression we return to the consideration of modern volcanic ejectamenta. The quantity of material extruded from the interior in the form of lava during some eruptions has been very great. The Vesuvian flows, extensive as many of them have been, are much inferior to those of the larger volcanoes of Europe and the East. For example, the stream which flowed from Etna and destroyed Catania in 1869 was fourteen miles long, and, in some parts, six miles wide. Other Etnean currents are described as fifteen, twenty, and even forty miles in length. The records of Icelandic eruptions are fortunately fairly complete, and they show that the energy of volcanic action in that region is very intense and has been displayed at frequent intervals. Some eruptions of Hecla have lasted six years continuously. The most stupendous outburst of modern times was the great eruption of Skaptár Jokul in 1783. A torrent of lava flowed from the volcano filling the channel of the Skaptà, and, spreading far and wide, carried destruction and devastation over large tracts of country. The volume of lava poured out during this eruption was extraordinary. Two branches flowed in opposite directions, one fifty miles in length, the other forty-five. The ordinary thickness of these great currents was about one hundred feet, and the width of one as much as twelve to fifteen miles, and the other about seven miles. It has been calculated that the mass of lava extruded from the interior on this occasion 'surpassed in magnitude the bulk of Mont Blanc.' Sir Charles Lyell, in his account of the eruption, endeavours to give an adequate impression of its magnitude by means of the following illustration[2]. 'A more distinct idea,' he says, 'will be formed of the dimensions of the two streams, if we consider how striking a feature they would now form in the geology of England, had they been poured out on the bottom of the sea after the deposition, and before the elevation of our Secondary and Tertiary rocks. The same causes which have excavated valleys through parts of our marine strata, once continuous, might have acted with equal force on the igneous rocks, leaving, at the same time, a sufficient portion undestroyed to enable us to discover their former extent. Let us, then, imagine the termination of the Skaptà branch of lava to rest on the escarpment of the inferior and middle oolite, where it commands the vale of Gloucester. The great platform might be 100 feet thick, and from 10 to 15 miles broad, exceeding any which can be found in Central France. We may also suppose great tabular masses to occur at intervals, capping the summit of the Cotswold Hills between Gloucester and Oxford, by Northleach, Burford, and other towns. The wide valley of the Oxford clay would then occasion an interruption for many miles; but the same rocks might recur on the summit of Cumnor and Shotover Hills, and all the other oolitic eminences of that district. On the chalk of Berkshire, other tabular masses six or seven miles wide might again be found; and, lastly, crowning the highest sands of Highgate and Hampstead, we might behold some remnants of the current 500 or 600 feet in thickness, causing those hills to rival or even to surpass in height, Salisbury Craigs and Arthur's Seat. The distance between the extreme points here indicated would not exceed ninety miles in a direct line; and we might then add, at the distance of nearly 200 miles from London along the coasts of Dorsetshire and Devonshire, for example, a great mass of igneous rocks, to represent the submarine reef of the Island of Nyöe.'

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[2] *Principles of Geology*, vol. ii. p. 51.

This outpouring of lava, stupendous as it was in quantity, is by no means unique, for flows of not less extent are recorded from some of the volcanoes of the East. During an eruption in the Island of Hawaii in 1855, a stream of lava sixty-five miles long, and from one to ten miles broad, was erupted. The conditions at present prevailing in the Hawaiian volcanoes are somewhat different from those of the European volcanoes, for they are distinguished by the quiet character of their eruptions. The volcanoes Mauna Loa and Kilauea have strictly speaking, no volcanic cone. The active crater, Kilauea, on the flank of Mauna Loa, is situated on an elevated plain; it is of irregular form and appears to have originated in a fissure which has been slowly enlarged by the liquid lavas encroaching upon it, and eating away its sides. The eruptions, instead of being (as in the case of Vesuvius) of an explosive character, with the ejection of dust, scoriæ, and other fragmentary materials, consist rather of a welling-up and outflowing of lava from the great crater cauldron. The molten material is exceptionally fluid, and is described as flowing like a great river several miles broad, expanding at times into lakes, and breaking up again into a network of streams, which burn their way through forests, and travel long distances.

This type of volcanic eruption brings us easily to the second great sub-division into which these subterranean manifestations have been divided: viz. *Fissure eruptions*—the slow welling-up and extrusion of molten lava from a fissure in the crust of the earth. There is every gradation between the restricted fissure, which is merely an orifice in the crust around which a volcanic cone is built up, and the long line of fissure, extending scores or hundreds of miles, which opens a way for the outpouring from the interior of lava in a quiet unexplosive fashion. Between these extremes we have examples of fissures which, instead of giving out lava along their whole length, are subject to explosive eruptions at different points, often successively, and giving rise to lines of volcanic cones in the way shown in the Lipari Islands, on the flanks of Etna, in Iceland, and elsewhere. The immense volume of the great Icelandic lava-flow of 1873, suggests, as Sir Archibald Geikie has pointed out, that some of the recent eruptions of that island may be rather of the character of 'fissure-eruptions,' than of the ordinary type in which the outpouring of lava is from a single volcanic vent. For the most stupendous examples of the results of 'fissure-eruptions' we must, however, turn to past geological times.

This brief account of the manifestations of subterranean energy, is sufficient to show the way in which new rock is added to the surface by extrusion from the interior. It is difficult to estimate with any degree of accuracy what the total result of this action is in the way of reproduction of land. Mr. Mallet, in his famous paper on Vulcanicity [3], made an attempt to estimate the total amount of ejected material represented by all the volcanic cones on the earth's surface. He took 400 as the total number of cones, and calculated that they averaged one mile in height, and five miles in diameter at the base. The volume of one such cone would be 6·54 cubic miles. As the cones are made up in the main of fragmentary materials—volcanic ash and scoriæ,—mere cinder-heaps in fact, he took the specific gravity as 2. This would give the quantity of material in one cone of the stated dimensions as 48,133 million tons. The 400 cones would therefore represent 2616 cubic miles, that is 19,200 billion tons of material ejected from the interior to the surface. This estimate no doubt falls far short of the actual total amount added to the surface by volcanic action; for it takes no account of the streams of lava that often extend to considerable distances from the volcanic mountains, or of the quantities of dust, scattered during great eruptions, far and wide over the earth's surface. It is indeed only by a detailed study of volcanic action in the past, as revealed by the records preserved amongst the various geological formations, that we can gain an adequate idea of the extent of the constructive action of the subterranean forces.

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[3] *Philosophical Transactions*, vol. clxiii. p. 167.

PART IV

EVOLUTION OF LAND-AREAS

'Nor is the value of the doctrine of Evolution to the philosophic thinker diminished by the fact that it applies the same method to the living and the not-living world; and embraces, in one stupendous analogy, the growth of a solar system from molecular chaos, the shaping of the earth from the nebulous cubhood of its youth, through innumerable changes and immeasurable ages, to its present form; and the development of a living being from the shapeless mass of protoplasm we term a germ.'—T. H. HUXLEY.

CHAPTER XII.

CLASSIFICATION AND INTERPRETATION OF THE STRATIFIED ROCKS.

BEFORE proceeding to explain the method of classifying and interpreting the stratified rocks, it will be convenient to define certain geological terms constantly in use. Beds inclined to the horizon are said to *dip*, and the amount of dip is expressed in terms of the angle which the inclination of the bed makes with the plane of the horizon (Fig. 25). The *strike* of beds is their extension laterally at right angles to the dip in the plane of bedding. The place where a bed comes to the surface is called its *outcrop*. When strata are bent or folded into an arch, the over-arching part is described as an *anticlinal* curve, and the under-arching portion as a *synclinal* curve

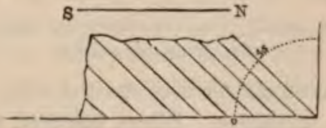

Fig. 25.—BEDS DIPPING NORTH AT AN ANGLE OF 45°.

(Fig. 26). A *fault* is a dislocation in which the beds on one side of a fissure are either elevated above or depressed below the beds on the other side, with which they were once continuous (Fig. 27). If an upper series of beds extends beyond the limits of those upon which it rests, so as to conceal their edges, it is said to *overlap*. Thus in Fig. 12 the limestone overlaps the clay, and the clay overlaps the sandstone. When, however, one group of strata rests by deposition upon the denuded edges of another group, the upper is said to be *unconformable* to the lower (Fig. 28).

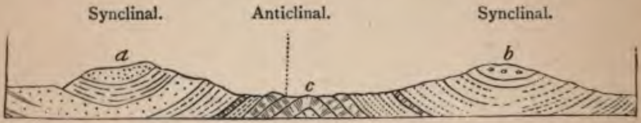

Fig. 26.—SECTION ACROSS PENDLE RANGE, LANCASHIRE.
(E. Hull.)
a. b. Yoredale grits and shales. *c.* Mountain limestone.

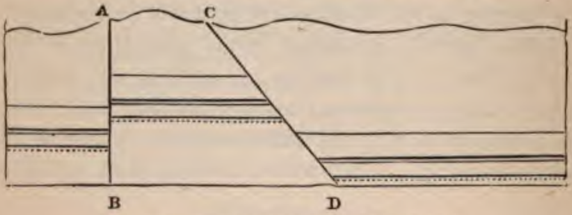

Fig. 27.—A. B. PERPENDICULAR FAULT.
C. D. OBLIQUE FAULT.

It will be seen that stratification and overlap, in which the beds rest regularly and conformably upon one another, merely imply simple movements of depression and subsequent elevation of the sea-bed, but dip, synclinal and anticlinal curves, and unconformability have a much deeper significance. This will be further explained and illustrated later on.

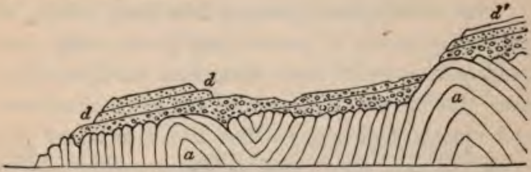

Fig. 28.—UNCONFORMABLE JUNCTION OF OLD RED SANDSTONE (*d*) AND SILURIAN (*a*) AT THE SICARR POINT, NEAR ST. ABB'S HEAD, BERWICKSHIRE.

The purpose of the geologist in studying the rocks of any area is twofold. He seeks in the first place to establish an order of superposition and succession of the beds, and to correlate those of different districts with one another.

In the second place he endeavours to learn from the study of the rocks and their contents—mineral and fossil—something as to the conditions under which they were formed, the distribution of land and water, and the nature and extent of the earth-movements, during and succeeding their formation, so as to restore the old physical geography of the period.

In working for the attainment of these ends there are three lines of study he may adopt, or three tests of age he may apply, which are embodied in the following three propositions.

(i) *That of two groups of strata the upper is the newer* (*except in cases of inverted strata*)*; in other words, as the* *sedimentary strata were laid down upon one another in a more or less horizontal position, the underlying beds must be older than those which cover them.*

(ii) *That strata may be identified by the assemblage of fossils they contain, each group of beds being characterised by particular species or genera, which are either entirely confined to it, or reach their maximum development in it; further, that the newer the strata, the more closely are the organic remains entombed in them allied to recent forms; the stratified rocks thus containing the records of a gradual progression of organic types, from less highly to more highly specialised forms.*

(iii) *That beds of the same lithological character were formed under similar physical conditions.*

These principles are of varying value, and their importance for one of the two purposes named is in inverse proportion to their importance for the other. For the purpose of establishing the order of succession and classifying beds in their order of age, the most important test is that indicated in the first proposition—viz. *Superposition.* If the movements to which strata have been subjected were simple upward movements elevating the deposits without disturbing them horizontally, there would be no difficulty in working out the order of superposition; but the movements have been of a complex character, due to lateral, tangential, thrusts, tilting and contorting the beds, so that after the removal, by the agents of denudation, of portions of these crumpled uplifted beds, it becomes often a matter of great difficulty to unravel the tangled skein of succession. Occasionally beds may be so folded as completely to invert the order, as in Fig. 29, where the Old Red Sandstone, which is really the lower, appears to overlie the Carboniferous. Among the older rocks cases of overfolding and inversion of a very complicated character frequently occur, rendering the interpretation excessively difficult.

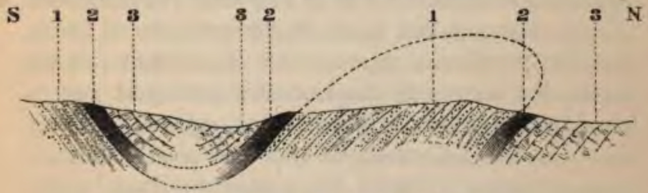

Fig. 29.—INVERTED BEDS NEAR MILFORD HAVEN.
(After Green).

1. Old Red Sandstone. 2. Lower Limestone Shale resting on old Red. 3. Carboniferous Limestone.

When the order of succession of the strata has been made out in any one region, the *Fossil contents* become a most valuable means of identifying the contemporaneous beds in other regions. In using the word 'contemporaneous' it must not, in its geological use, be taken to mean strictly synchronous, for all we have a right to express by the term is that beds in two regions have the same order of succession, not necessarily that each corresponding division was deposited at exactly the same time. Whewell long ago[1] pointed out that the members of two corresponding series of rocks in different countries should be considered as *representatives* or *equivalents* rather than identical in age; but the word *homotaxis* (similarity of order), subsequently proposed by Professor Huxley, has now been very generally adopted.

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[1] *Hist. Induct. Sciences*, vol. iii. p. 533.

The recognition of the importance of *Fossil contents*, as a test of age of strata, is due to William Smith, the father of English Geology, as he was called by Sedgwick. He published in 1790 a tabular view of the British strata, in which he proposed a classification of the Secondary rocks of the West of England. He established the fact that each bed might be identified by its fossils, and that there was a regular order of succession in the beds. He afterwards constructed a geological map of the whole of England, which was completed in 1815, and was the first work of the kind ever published. Since the days of Smith the method initiated by him has been further perfected, and later research has confirmed the soundness and far-sightedness of his main conclusions. The detailed and elaborate study of particular groups which it has been possible to make has shown that not only are the larger sub-divisions characterised by their own peculiar species and genera, but that particular horizons may also be distinguished by forms which are strictly limited to them. For example, it has long been known that the Lias is divisible into zones, each characterised by one or more species of ammonite. The Chalk may in like manner be divided into zones, each recognisable by one or more species of fossils confined to it, and researches among the Palæozoic rocks point to a similar state of things in the oldest fossiliferous strata. Thus it is shown that the same principle prevails throughout the geological series.

If the object of the geologist however is not so much to classify the beds as to reconstruct the old Physical Geography and to restore in imagination the conditions that prevailed during the deposition of the beds, *Lithological character* is of supreme importance, for the nature of the sedimentary deposit is, as we have already seen, dependent upon depth of water and relation to the shore line. Throughout the geological series we find the common recurrence of a threefold arrangement of strata in which sandstone, clay, and limestone form a regular succession. For example, the Old Red Sandstone is in some areas succeeded by the Lower Limestone shale and that by the Mountain Limestone which passes up through the Yoredale limestones, shales, and sandstones into the Millstone grit. Again, the Triassic sandstones underlie the Lias clay which passes up into the limestone of the inferior Oolite. The Lower Greensand, Gault clay, and Chalk form a similar series. This succession points to subsidence in the area. The sandstones, indicating proximity to land, gave place, as the sea-bed subsided and the water deepened, to clays and shales, while these in their turn were covered by limestones as subsidence led to an increased remoteness from land, the source of sediment, and consequently to greater clearness of water. Then when an upward movement began or the sea-bed became silted up by continued accumulation, the limestones in their turn were covered by clays and sandstones indicative again of shallower water and proximity to land. Thus the cycle of sedimentation was repeated over and over again.

From the character and affinities of the forms of life entombed in the strata also much may be learnt as to the conditions that prevailed during deposition. The presence of fresh-water forms, with occasional remains of land animals and plants, indicate lacustrine or fluviatile conditions. Marine forms may be of shallow-water or deep-water varieties, and of tropical or boreal affinities, and may thus throw light upon the climatal conditions prevailing at the time of the deposition of the beds.

The features most significant of large changes in Physical Geography are *Unconformabilities*, for they indicate a transition from marine to terrestrial conditions by upheaval of the sea-bed. An Unconformability necessarily implies extensive movements in the crust, generally crumpling, and contorting the strata during their elevation into land, followed by their denudation and subsequent depression to form again a sea-bed on which newer strata were laid down upon their denuded edges. The term *Stratigraphical break* is frequently used as synonymous with Unconformability, and it will be evident that the phenomenon is of paramount importance for classificatory purposes. A *Stratigraphical break* is always associated with a more or less pronounced *Palæontological break*—that is, a marked difference in the character of the assemblage of fossils characterising the successive beds, indicating either the lapse of an interval of time unrepresented by deposits at the place where the 'break' occurs, or changes in physical conditions leading to the extinction of the old forms or their migration into other areas, and the migration of new forms into the area to take their place. It is hardly necessary to point out that, if the whole of the strata ever deposited on the earth's surface were preserved and open to examination, all the 'breaks' would be found to be local, and would be bridged over by beds deposited in other regions. When the sea-bed in one region was upheaved into land, the deposition of material was continued in neighbouring seas until by a later subsidence the region again came to form part of the sea-bed upon which newer deposits were laid down. The strata formed in the neighbouring seas would thus represent the interval during which terrestrial conditions prevailed, to the existence of which the unconformability of the beds would bear conclusive testimony.

The principle upon which the Stratified Rocks are classified into divisions, systems, and smaller groups may be stated as follows:—

Those beds are grouped together which by their lithological character, relation to one another, and fossil contents, are shown to have been deposited under the same continuous physical conditions; in other words, the groups are separated by stratigraphical or palæontological 'breaks.'

It will be evident from what has been said in earlier pages that continuous deposition does not necessarily imply *similarity* of lithological character. In point of fact lithological changes will show themselves in a subsiding area in accordance with the principle of sedimentation already explained. When a continental area is slowly subsiding it is obvious that as the sea creeps up its slopes and each portion successively disappears below the surface, deposits of coarse sedimentary material, the result of the abrading action of the waves upon the shore, will first be laid down upon the newly formed sea-bed. These in their turn will be covered with other deposits finer in character or possibly not sedimentary at all but calcareous. If, when the land had completely disappeared, we were able to take a cut through the whole, so as to obtain a section showing the relation of the newer beds to those older rocks of which the surface of the continental area had been composed, we should find the newer resting *unconformably* on the older. The surface of the older rocks would show signs of the denudation which the area had suffered while the land conditions prevailed, and that would necessarily imply a lapse of time during which the older rocks had been uplifted into a continental area, had been subjected to the attacks of rain, frost, and the other agents of destruction, and had again undergone depression to form a fresh sea-bed. If we examined the newer strata alone we should find that although they consisted of deposits of varying lithological character, here a coarse conglomerate, there a clay—in one place a coral reef, in another a shell-bank, still the whole was continuous and had been deposited during the one period of depression; in the succession we should find no *unconformability*[1].

The most important lines of demarcation in the Stratified Rocks are drawn where the largest stratigraphical and palæontological 'breaks' occur, and it is usual to divide them into four great divisions: (1) Archæan, (2) Palæozoic (ancient life) or Primary, (3) Mesozoic (middle life) or Secondary, and (4) Cainozoic (recent life) or Tertiary (Plate VIII and Table II, p. 181).

In the Table of Strata (p. 181) it will be seen that an attempt is made to indicate the proportional magnitude of the principal 'breaks,' as far as they can be determined, from evidence afforded by the denudation of rock masses during the existence of the land conditions indicated by the unconformability.

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[1] *Proc. Camb. Phil. Soc.* vol. iii. pt. vi. 'On the relation of the appearance of the various forms of life upon the earth to the breaks in the continuity of sedimentary strata,' by Prof. T. McK. Hughes, F.R.S.

One of the most important stratigraphical 'breaks' is that between the Carboniferous and Permian (Lower Poikilitic). The existence of this 'break' is proved by the fact that the Permian beds rest upon the denuded edges of *Lower* Carboniferous. At Low Moor, near Clitheroe, the Permian red sandstones rests upon contorted and denuded Carboniferous Limestone—the lowest member of the Carboniferous series—instead of upon the uppermost member—the Coal-measures—as might have been expected. The thickness of the missing beds, as they occur in other parts of that area has been estimated as follows, though perhaps the estimate may be rather too high :—

Coal-measures	8,400	feet.
Millstone Grit	5,500	,,
Yoredale Series . . .	5,000	,,
Carboniferous Limestone, in part	250	,,
	19,150	,,

Thus we see that after the deposition of the Upper Coal-measures there was an upheaval of the beds, and a removal by denudation of over 19,000 feet of strata before the subsidence occurred which led to the deposition of the Permian red sandstones upon the denuded Limestone beds as we now find them.

It is interesting to note that while the more marked 'stratigraphical break' occurs between the Carboniferous and Permian, the 'palæontological break' is more pronounced between the Permian and Trias, and it has therefore been usual to draw the line between the Palæozoic and Mesozoic divisions above the Permian and below the Trias. Seeing however how enormous the 'stratigraphical break' is between the Carboniferous and Permian, it seems more in accordance with the facts to group the beds as is done in Table II. The apparent discrepancy between these two classes of evidence is not difficult to explain. When the Upper Carboniferous sea-bed was upheaved into land, the marine fauna (the total assemblage of living forms) inhabiting the Carboniferous sea migrated to other areas, where, under the spur of changing physical conditions and competition with other forms, the fauna underwent much modification. Some types succumbed and disappeared for ever. Others were able to hold their own with some amount of change, and when the continental land into which the Carboniferous sea-bed had been upraised was again depressed and the sea spread over it, the marine fauna, much modified in the interval, migrated back. Finally, as physical changes continued and the Permian sea became an inland salt lake, the modification of organic forms was still further carried on, and by the time the Triassic beds were laid down there was little trace of the Carboniferous fauna left.

The question may here well be asked: If the difference between the fauna of the Palæozoic and Mesozoic periods is so much greater than the difference between the fauna of the bottom and top beds of the Palæozoic itself, are we justified in assuming that the interval of time represented by the 'palæontological break' between the Palæozoic and Mesozoic, during which the change in the fauna took place, is proportionally greater than the interval represented by the deposition of the Palæozoic strata from the Harlech grits to the Coal-measures inclusive?

To that question it seems clear a negative answer should be given. If it be answered affirmatively we are bound to assume a *uniform* rate of evolution. There is good reason however for supposing that the evolution of the organic world is not uniform but has its periods of rapid movement and its periods of comparative repose and re-adjustment of equilibrium. Living forms are subject to the action of two sets of forces—(i) *external* and (ii) *internal*. Climatal and other physical changes in the conditions of life undoubtedly affect the organism profoundly. On the other hand, internal forces are at work. There appears to be in living forms an *inherent tendency to change*, and also *an inherent tendency to stability*. Thus an organism is under the influence of two opposing forces—the one *progressive*, a tendency to motion, the other *conservative*, a tendency to equilibrium. External changes in climate or in environment stimulate the tendency to change, and under such circumstances evolution would be likely to be rapid, while under normal and unvarying external conditions the tendency to stability—the law of heredity—would be the dominant influence and the evolution would be slow or not apparent. We should expect therefore that evolution would be paroxysmal, and indeed we have every reason for supposing that the derivation of one species from another is not necessarily by innumerable imperceptible steps, but may, at any rate sometimes, be by a few decided steps. Since therefore a 'stratigraphical break' denotes a period of large physical change in the earth's crust, the elevation of sea-beds into land, and redistribution of land and water involving doubtless important changes in climatal conditions, it is natural that the evolution of living forms should be more rapid at such times than during the slow quiet deposition of stratum upon stratum in regular conformable succession. Mr. Le Conte, in a highly suggestive and interesting treatment of this question, has proposed for such periods of change the name 'Critical periods.'

'Other kinds of evolution (he says) physical and social evidently advance paroxysmally. As therefore in the gradual evolution of earth features there were periods of comparative quiet when the forces were gathering strength, without producing any visible effect, being resisted by crust rigidity, and periods when the accumulating forces finally overcame resistance and determined rapid changes; as also in social evolution there are periods in which forces of social change are gathering strength but make no visible sign, being resisted by social conservatism—rigidity of the social crust—and periods in which resistance gives way and rapid changes occur; so also in the evolution of the organic kingdom the forces of changes, i. e. pressure of changing environment may accumulate but make little impression, being resisted by the *law of heredity*—of like producing like, or type rigidity, until finally the resistance giving way the organic forms break into fantastic sports which are at once seized by natural selection, and rapid change is the result. On the supposition of such rigidity—or resistance to change in organic forms varying in degree in different species and genera, a rigidity also increasing by accumulated heredity as long as conditions remain unchanged, it is evident that in times of perfect tranquillity all species grow more and more rigid. In times of very gradual change, the more plastic species change gradually *pari passu*, while the more rigid species change paroxysmally now one now another, as their resistance is overcome. Finally, in times of revolution nearly all forms yield to the pressure of external conditions and change rapidly, only the very exceptionally rigid being able to pass over the interval to the next period of readjusted equilibrum[3].'

Turning again to Table II (p. 181), and comparing it with the table on the Geological Map (Plate VIII), where the large divisions, Palæozoic, Mesozoic, and Tertiary are also indicated, it will be noted that such a mode of tabulation as that on the Geological Map fails to convey to the mind the relative importance and magnitude of those divisions in the way clearly shown by Table II. It is at once obvious from the Table that these divisions do not represent periods of equal length. The Palæozoic is enormously more extensive, both in the thickness of its strata and in the number and importance of its breaks, than the Mesozoic and Tertiary; and, in like manner, the palæontological changes in the various subdivisions of the Palæozoic are far more striking than in the later beds.

The Palæozoic rocks have undergone more alteration, and have been subjected to greater movement and subsequent denudation than the newer beds, and therefore present greater difficulties of classification than the Mesozoic and Tertiary beds. It is not surprising therefore that there should still be differences of opinion as to the grouping and nomenclature of many of the strata. The classification of the *Cambrian* and *Silurian* beds has been subject of controversy ever since they were first studied and described by Professor Sedgwick and Sir Roderick Murchison. The classification adopted in Table II is that of Professor Sedgwick. By many geologists the term *Cambrian* is limited to the beds from the Arenig to the Harlech, while those from the Arenig to the top of the Bala are denominated *Ordovican*.

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[3] *Amer. Jour. of Science*, 3rd series, vol. xiv. (1877), p. 99, 'Unconformities and Evolution,' by J. Le Conte.

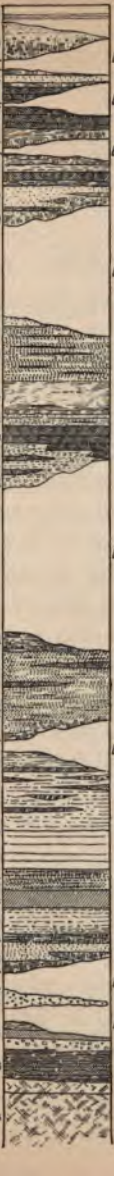
The scope and purpose of this volume does not admit of a detailed description of the various groups of the geological series. That can be found in any standard text-book on Geology. What is sought here is to indicate the way in which the lithological character, fossil contents, and petrographical relations of strata may be interpreted, so as to work out the earth's history.

In the next chapter we shall show how the lithological character of the beds, from the Cambrian conglomerate to the newest Tertiary, furnish proof of a recurrence of similar physical conditions to those existing at the present day, under which the various accumulations are being laid down around or upon the continental areas and in the deep sea.

The Table given on the following page shows the CLASSIFICATION OF THE STRATIFIED ROCKS ACCORDING TO AGE. (Scale, 1 inch to 16,000 feet. *Maximum European thickness taken.*)

TABLE II.

SOME CHARACTERISTICS OF THE BRITISH BEDS.



CAINOZOIC or	TERTIARY	Pliocene Miocene		On the continent great masses of sandstones and glomerate. In Britain only a few doubtful patche hollows on an old land Surface. Volcanic action.
			Break	
		Oligocene & Eocene		Volcanic action on a grand scale in W. Scotland N. Ireland. Alternations of shore and estuarine, fr water, and marine conditions.
			Break	
MESOZOIC	CRETACEOUS &C.	Cretaceous		Open sea conditions in South ; estuarine condition North, in Scotland.
		Neocomian		Delta deposit in South, in Weald area ; marine clay N. in Yorkshire.
			Break	
	JURASSIC &C.	Jurassic		Alternations of clays and limestones derived from bro corals and shells indicating more open Sea towards estuarine conditions towards N. E.
		New red or Poikilitic { Up^r (= Trias) L^r (= Permian)		Mainly red sandstones.
			Break	
PALÆOZOIC	CARBONIFEROUS & DEVONIAN	Coal Measures		Alternations of shales, sandstones, ironstones with se of coal. Interbedded and intrusive volcanic rock Scotland proving enormous volcanic activity.
		Millstone Grit		Grits and sandstones.
		Yoredale Rocks Mountain Limestone		Limestone, pure in Derbyshire becomes more more impure with sedimentary material when tra North showing estuarine conditions, and proving the land lay to the North.
		Devonian Upper Old red		Red sandstones and conglomerates. Vigorous volc action in Lower Old Red in Scotland.
			Break	Very strongly marked in Scotland, N. Wales, N England, and S.W. Ireland.
	SILURIAN	Lower Old red Ledbury Shales, &c. Ludlow Wenlock May Hill Up^r L^r		Higher beds of Silurian seen in S Wales than N. Wales. In Ireland the beds consist of conglon ates and grits with lavas and volcanic agglomera No volcanic action in Great Britain.
			Break	
	CAMBRIAN	Upper Bala		Fine sandy mud with rarely thin limestones.
				Great Volcanic series in N. Wales and Lake Distric
		Lower Bala		Sandy mud forming black slates and flags.
		Arenig		Intercalations of volcanic ashes, tuffs and lavas.
		Tremadoc Lingula Flags Menevian Harlech Beds		Sand and shingle varying according to local ori and resting irregularly on Pre-Cambrian.
			Break	
ARCHÆAN or	PRE-CAMBRIAN	Torridonian		Sandstone in N. W. Scotland.
			Break	
		Bangor Rocks		Volcanic Slates and agglomerates.
		Dinorwig Rocks		Lavas.
		Carnarvon Rocks		Various Gneissic and Granitoid Rocks.

CHAPTER XIII.

THE AQUEOUS ROCKS AND DEPOSITION IN PAST TIMES.

IN the rocks composing continental land, we find representatives of all the various deposits described in previous chapters, with the exception of the abysmal deposits of Red Clay and Radiolarian ooze. So far no beds have been detected in the great continental areas of this character, and presumably formed under the same conditions. Mr. Guppy records, however, the discovery in one of the Solomon Islands in the Western Pacific of a Globigerina limestone similar to that found in modern seas at depths of 500 to 800 fathoms. In another island a rock resembling a deep-sea clay was found underlying a coral limestone. The foraminifera in the clay were few in number and for the most part in the rotten corroded condition characteristic of those which occur at depths exceeding 2000 fathoms[1]. Similar deep-sea types of deposits have been found among the West Indian Tertiary beds[2]. The other sedimentary and calcareous accumulations can be paralleled in almost every sub-division of the Stratified rocks.

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[1] *The Solomon Islands*, by H. B. GUPPY, M.B., pp. 73, 81.

[2] *Quart. Journ. Geol. Soc.* vol. xlviii. (1892) p. 17. The Geology of Barbadoes (Part II. Oceanic Deposits), by A. J. JUKES-BROWNE, B.A., and Prof. J. B. HARRISON, M.A.

In the classification of the rocks of the crust, according to mode of origin given in Table III, p. 201, the Aqueous or Stratified rocks are divided into three groups. Considering first the Mechanically-formed, we have many examples of massive conglomerates made up of rounded pebbles indicating by their nature and position that they are old shingle beaches. At the base of the Cambrian beds a conglomerate almost universally occurs resting upon the older pre-Cambrian rocks. The pebbles of which it is made up are as a rule fragments of the more ancient rocks upon which it rests, brought down by rivers or torn in olden time from shore cliffs by the action of atmospheric and marine destructive agents, as we see similar shingle formed to-day around our own rocky coasts.

Wherever masses of ancient rocks are surrounded by newer rocks, there we may usually discover conglomerates at the base of the newer, resting upon an old shore-line. On the west side of the Malvern Hills a conglomerate forming the base of the Silurian beds of that area, may be traced clinging to the surface of the pre-Cambrian ridge, and made up largely of pebbles of pre-Cambrian rocks, intermingled with which shells and other marine fossils occur just as they might do in pebbly accumulations of the present day. In other parts of that district where New Red Sandstone beds abut upon the pre-Cambrian ridge, similar conglomeratic beds of New Red Sandstone age occur. It is worthy of remark that the points at which these conglomerates occur 'are all in situations which were, or may be believed to have been, bays or sheltered parts of the ancient sea-coast line; that the constituent fragments which abound in the conglomerate are very rarely rolled to spheroidal masses, and often only blunted at the angles; and that the two most conspicuous masses, viz. that south of the Malverns, and that of the Teme Valley, decline rapidly toward the south. We may conclude from these facts, that the main set of the sea currents against the Malvern Hills, in the earliest Red Sandstone period [referring to the New Red Sandstone], was from north to south; that the materials derived from the waste of the adjoining lands were drifted southwards to places of rest, such as bays and the depressions of valleys might yield, while the exposed coast of the Malvern ridge, which was raked by the current, and offered no sheltering hollows, was in a great degree deprived of these deposits?'[3]

Some of the finest examples of conglomeratic deposits in Great Britain, remarkable for their immense thickness and wide extent, occur in the Old Red Sandstone series of Scotland. The beds, composed of huge blocks of the older rocks of North Scotland—gneisses and schists—are piled up to a thickness of between one and two thousand feet, testifying to the enormous denudation of the Highlands in those times. The importance of the rocks we are now dealing with, from the point of view of the restoration of the old physical conditions, is obvious. Wherever a massive conglomerate occurs we know that we are upon the beach of an ancient land-area. From a study of the pebbles we may learn something as to the character of the rocks that then constituted the land; and we know further that a subsidence of the area must have been taking place to allow the sea to creep up the slopes to form these ancient shore deposits.

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[3] *Memoirs of the Geol. Survey of Great Britain*, vol. ii. part i. p. 113.

Conglomeratic accumulations however such as these, form but a small proportion of the rocks composing the crust; the finer arenaceous deposits of grits and sandstones are far more abundant and occur in great variety, and of all ages. Throughout the Palæozoic Series beds of sandstone of enormous thickness occur, such as the Caradoc 10,000 to 12,000 feet, the Old Red Sandstone about 10,000 feet and the Carboniferous grits and sandstones, many thousands of feet thick.

Much may be learnt as to the conditions of deposition, from microscopical study of the grains of sand composing these rocks, as Dr. Sorby's valuable researches have shown[1]. It is important to distinguish between the age of the grains and the age of the deposit in which they occur. A sandstone, itself ancient, may be composed of grains which were at the time of deposition practically new and unworn, while, on the other hand, the grains of a modern sea-shore may be of vast antiquity, and may have undergone generations of wearing—may indeed have formed part successively of several geological formations in past times. Grains, when first broken off from the parent rock, will necessarily be angular, but we have not yet sufficient evidence to show how long it takes by wearing down to convert angular grains of different material into rounded grains. It is unquestionably a slow and gradual process. Dr. Sorby's examination of various sandstones led to highly interesting results, throwing much light upon ancient conditions of deposition. For example, a comparison of the Greensand (Cretaceous) of Devonshire with that of Kent showed that while at Haldon Hill, in Devonshire, the grains were mostly angular, only one in ten of those examined being well worn, in the similar beds in the Isle of Wight, the proportion proved to be one in five well-worn, whilst in Sussex and Kent it became one in three, and one in two. Thus from the progressive increase in the worn and rounded character of the grains as the beds are followed from Devonshire to Kent, Dr. Sorby inferred that they were derived from the granite rocks of Dartmoor, and in drifting further and further towards the east had become more and more rounded and worn.

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[1] *Quart. Journ. Geol. Soc.*, vol. xxxvi. Presidential Address, by H. Clifton Sorby, LL.D.

Modern sands are found to vary considerably in character; that of the Thames near Richmond, for example, consists of about one grain in two well-worn, which is in striking contrast with the perfect angularity of the sand grains of the Tay, and clearly indicates the high antiquity of the grains of the Thames bed, and the great distance to which at one time or other they have been drifted from their original source in more ancient rocks.

Certain sandstones, notably those of the Old and New Red Sandstone, are red in colour, due to fine pellicles of oxide of iron around the grains. This circumstance, with other evidence, tends to show that these Red Sandstones were formed in inland lakes or seas. In the case of the Old Red beds the absence of marine forms of life, and the presence of fish of fresh-water affinities, together with occasional plant-remains, afford conclusive proof of their lacustrine origin. The actual boundaries and positions of four ancient lakes in Scotland and one in Wales, in which the Old Red Sandstone beds were laid down have been traced[5]. 'Even now,' says Sir A. Geikie, 'we can trace some of their shore-lines, walk over the shingle of their beaches, examine the silt of their deeper gulfs, and exhume the remains of the plants that shaded their borders, as well as of the fishes that swarmed in their waters. The sediments which accumulated in some of these basins amount to many thousand feet in thickness; yet from bottom to top they abound in evidence of shallow water conditions of deposition. We are thus led to infer that the disturbance of the crust which brought about the formation of the hollows continued for a vast interval, the floors of the basins sinking and the intervening tracts being ridged up as the results of one great movement of the terrestrial crust, while at the same time the surface of the land was undergoing extensive denudation, and the basins were receiving a constant influx of sediment[6].'

In the case of the New Red Sandstone, the absence of fossils and the presence of deposits of salt, alternating with sedimentary beds, point to their origin in inland salt lakes, like the Caspian Sea or the great Salt Lake.

That these old lakes were in the main shallow is proved by the ripple-marks, sun-cracks, and in some cases tracks of animals preserved on the sandstone beds. The entire surface of the slabs may frequently be ridged and furrowed, like a bank of sand just left by the tide (Fig. 30). In some cases the furrows are intersected by cross ripples, evidently due to changes in the direction of the moving water. The perfect analogy between these markings and those produced by undulations of water on the surface of sand and mud shallows, proves that the markings are due to the same cause. Of still greater interest are sun-cracks, as showing that the beds were at intervals exposed by the recession of the water, possibly during seasonal periods of drought. They take the form of slightly elevated longitudinal ridges, irregularly crossing one another, evidently formed by the deposition of sand in cracks, opened by the surface drying in the sun's heat (Fig. 31). Still more striking are the impressions of rain-drops, found on some of the finer beds

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[5] *Edinburgh Philosophical Transactions*, vol. xxviii. 'The O Red Sandstone,' Sir A. Geikie.

[6] Presidential Address, Geol. Soc. 1892, p. 39.

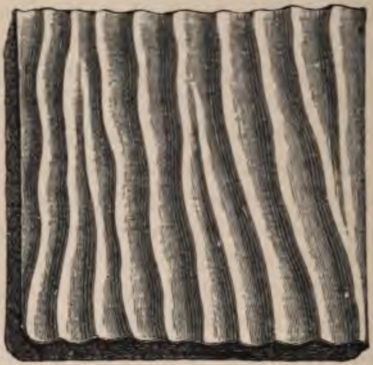
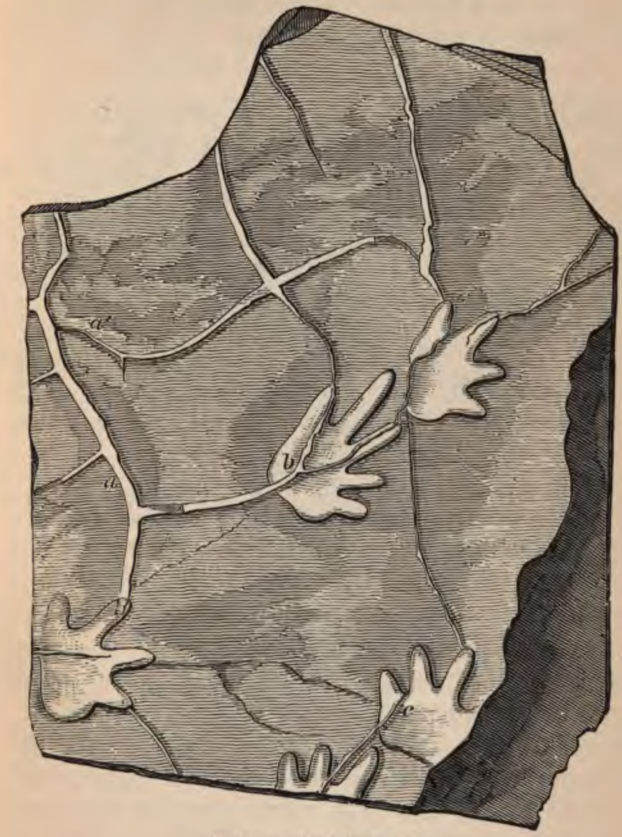


Fig. 30.—SLAB OF RIPPLE-MARKED (NEW RED) SANDSTONE FROM CHESHIRE.



Scale: one-sixth the original.

Fig. 31.—SLAB OF SANDSTONE FROM THE COAL-MEASURES OF PENNYSYLVANIA WITH *b*, *c* FOOTPRINTS OF AIR-BREATHING AMPHIBIAN AND *a*, *a'* SUN-CRACKS.

(Fig. 32), and the trails of worms and crustacea, with the footprints of vertebrate creatures. An impressive in-

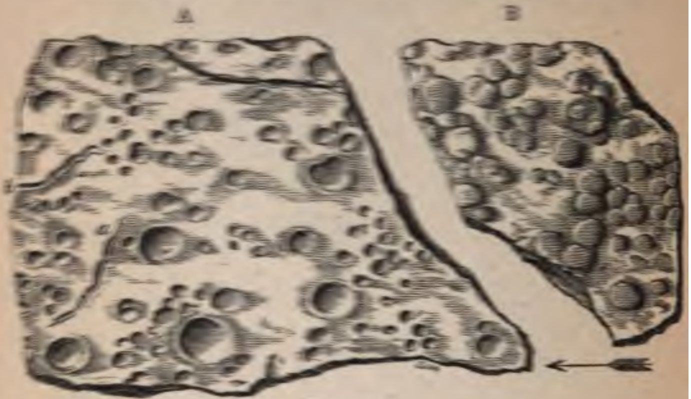


Fig. 32.

A.—CARBONIFEROUS RAIN-PRINTS WITH WORM-TRACKS (*a*, *b*), ON GREEN SHALE, FROM CAPE BRETON, NOVA SCOTIA.

B.—CASTS OF RAIN-PRINTS ON A PORTION OF THE SAME SLAB SEEN TO PROJECT ON THE UNDERSIDE OF AN INCUMBENT LAYER OF ARENACEOUS SHALE.

Natural size. The arrow represents the supposed direction of the shower.

stance of fossil footprints is furnished by the New Red Sandstones of Connecticut where impressions of three-toed feet, as of birds, have been observed in great numbers. It is possible that some of them may be reptilian; but their likeness to those of birds is unmistakable (Fig. 33). The picture they call up before the mind of conditions that prevailed in New Red Sandstone times is vividly portrayed in the following striking passage by a master of picturesque description:

'They are fraught with strange meanings these footprints of the Connecticut. They tell of a time far removed into the by-past eternity, when great birds frequented by myriads the shores of a nameless lake, to wade into its shallows in quest of mail-covered fishes of the ancient type, or long-extinct molluscs; while reptiles, equally gigantic, and of still stranger proportions, haunted the neighbouring swamps and savannahs; and when the

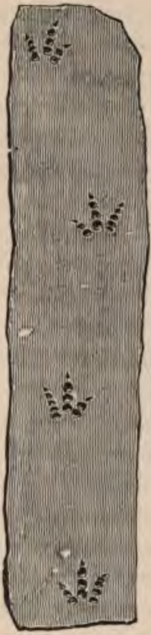


Fig. 33.—FOOTPRINTS, TURNER'S FALLS, VALLEY OF THE CONNECTICUT.

same sun that shone on the tall moving forms beside the waters, and threw their long shadows across the red sands, lighted up the glades of deep forests, all of whose fantastic productions—tree, bush, and herb—have even in their very species long since passed away. And of this scene of things only the footprints remain—"footprints on the sands of time.[7]"'

Some conception of the enormous mass of material represented by the great sandstone and shaly deposits of only a part of the Palæozoic rocks may be gained from the following facts.

If we regard the Cambrian and Silurian beds from the Arenig to the Ludlow, we have a thickness of 16,000 feet (nearly three miles) covering an area in the British Isles alone of at least 60,000 square miles, and making a total quantity of material of no less than 180,000 cubic miles. This is taking account of the exposed part only; how much may be concealed under new rocks it is impossible to say. This mass would suffice to form a mountain range 1,800 miles long, say from the North Cape to Marseilles, with a breadth of 100 miles, and an average height of 16,000 feet, *i.e.* exceeding the altitude of Mont Blanc. These beds are in the main grits and sandstones, often ripple-marked, showing that the water was on the whole shallow. The maintenance of these shallow conditions during the accumulation of deposits three miles thick, necessarily implies a continuous subsidence of the sea-bed, broken no doubt occasionally by pauses, or even temporary uprisings. These sinkings, pauses, and uprisings are all indicated by changes in the character of the deposits.

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[7] *Testimony of the Rocks*, by HUGH MILLER, p. 83.

Passing on to consider the finer materials deposited at a greater distance from shore, we meet in the crust of the earth with the frequent occurrence of beds of clay and shale. The greater induration of the rocks in the older formations presents these deposits of finer material in the form of shales, while in Mesozoic and later times they occur as clays like the Lias, Oxford, and London clays. As a rule these beds are shown by their fossil contents to have been marine; but occasionally, and particularly in the case of the Weald clay, we are furnished with an extremely interesting example of a deposit laid down under fresh-water conditions comparable to those under which existing deltas are being formed. This series of beds, with a total thickness of 1500 feet, comprises two main sub-divisions, the lower or Hastings sand, and the upper or Weald clay. The latter consist in the main of blue or brown clay, with occasional bands of shelly limestone and sandstone. The limestone is made up of the shells of Paludina, a fresh-water univalve, while the sandstone is marked by the occurrence in it of ironstone nodules. That these beds were deposited in shallow water is proved by remarkably perfect ripple-marking, sun-cracks, worm-trails, and reptilian footprints. Another striking feature exhibited by these Weald beds is the suddenness with which the lithological character of the sediment changes. Coarse conglomerates may be covered by sand or finely laminated clay or shale (Fig. 34), precisely similar to the condition of things revealed by the borings in the delta of the Ganges and Brahmapootra referred to in a previous chapter. There can be little question that we have in the Wealden beds an old delta deposit, although it is open to question whether this delta may not have been formed in an ancient lake and not in an estuary. The fact that all the organic remains are of fresh-water forms, without alternations of brackish or marine forms, seems to show that no inroads of sea-water occurred during the deposition of these beds, and suggests a lacustrine origin. This is in marked contrast with the Purbeck series underlying them, in which beds containing marine and fresh-water fossils occur alternately, and point to deposition in lagoons gradually cut off from the sea by upheaval, and eventually resulting in land conditions, as shown by the 'dirt-beds' containing stools of trees in the soils in which they grew (Fig. 35).

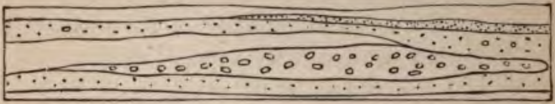

Fig. 34.—SECTION OF STRATA OF SHALE, SANDSTONE, GRIT, AND CONGLOMERATE.

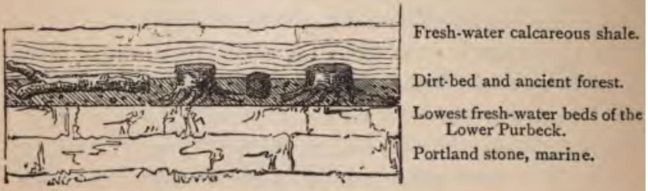
Fresh-water calcareous shale.
Dirt-bed and ancient forest.
Lowest fresh-water beds of the Lower Purbeck.
Portland stone, marine.

Fig. 35.—SECTION OF PURBECK BEDS, ISLE OF PORTLAND, DORSET.

By the time of the beginning of the deposition of the

Wealden beds, the area of south-east England had become a great lake, into which rivers from the neighbouring lands brought the sediment that accumulated to form these deposits. That the lake was a very extensive one is shown by the fact that the Wealden Strata now exposed occur not only in Kent, Surrey, and Hampshire, but extend to the north of France, covering an area 200 miles by 100, with a superficies of 20,000 square miles. It is highly probable that the beds extended originally even further than they can now be traced, and the delta may have once covered an area of even 30,000 square miles. Great as this seems, it falls short of the united delta of the Ganges and Brahmapootra, the superficial area of which is 40,000 square miles.

It now remains to consider the examples of calcareous deposits due to marine organisms, which occur in the crust in great variety and of enormous thickness. Limestones made up of univalve and bivalve shells, others composed of encrinital remains, and of coral and foraminiferal accumulations, are all well represented. The shelly limestones frequently occur alternating with sandstone and clay, an arrangement that indicates oscillations of level or the prevalence of physical conditions only temporarily favourable to the accumulation of organic remains.

In the great and thick limestone beds like the Carboniferous Limestone, the Jurassic Limestones, and the Chalk, we have masses of strata formed under long continued conditions of clear, comparatively deep water, cut off from sources of sediment. Parts of the Carboniferous Limestone, and the Corallian limestones of the

Jurassic series, are accumulations of coral, veritable old coral reefs, similar in every respect to those now forming in tropical waters. There can be little doubt that in Jurassic times a great part of the British area was covered by a warm sea where corals flourished and conditions obtained similar to those now prevailing in parts of the Indian and Pacific Oceans. The closeness of the resemblance is shown by the preservation in the Gloucestershire oolites of turtles' eggs in the limestone. These eggs, eight in number, each measuring 1¾ inches long, were discovered in a very white cream-coloured freestone, exhibiting false-bedding and pseudo-ripple-marks. These characters, together with the presence of abundant fragments of fossil-wood, testify to the shallowness of the water in which the beds were laid down, and prove that in the coral-sand of these old reefs turtles laid their eggs as they do now on the shores of reefs in the Pacific[8].

The Chalk is a limestone which presents many features of extreme interest. In the first place it offers strong points of resemblance to the Globigerina ooze which deep-sea explorations have shown to cover so large a part of the Atlantic and Pacific. It is largely made up of foraminiferal shells of the same genera and even species as those occurring in the Globigerina ooze. In hand specimens the dried ooze can with difficulty be distinguished from many samples of chalk. It would be a mistake however to insist unduly upon resemblances to the exclusion of certain important differences. A comparison of the chemical composition of chalk with that of Globigerina ooze, brings out the important fact that chalk is more nearly pure calcium carbonate than the ooze, alumina and silica being present only in small quantity. Chalk consists of 94 to 99 per cent. of calcium carbonate and mere traces of alumina and silica; while Globigerina ooze consists of only 44 to 79 per cent. of calcium carbonate, 5 to 11 per cent. of silica, and 8 to 33 per cent. of alumina and oxide of iron. In point of fact calcareous deposits found near shore round coral islands show a much closer resemblance chemically to chalk than does the Globigerina ooze, and Dr. Murray has emphasised the fact that Globigerina ooze obtained from shallow parts of the sea-bed resembles chalk much more than that from depths over 1000 fathoms. Mr. Gwyn Jeffreys many years ago expressed the opinion, founded upon a study of the molluscan shells of the Chalk, that it could not have been a very deep sea deposit, seeing that of the seventy-one species, all were comparatively shallow-water forms, many living at depths not exceeding forty to fifty fathoms. Despite these differences the broad features of the two deposits are so much alike that we may rightly regard the Globigerina ooze as the modern representative of the Chalk; but the sea in which the Chalk was formed was probably a more or less land-locked sea like the Mediterranean, rather than an open ocean like the Atlantic. The wide distribution of the Chalk, stretching as it does from north-west Ireland, through France, Denmark and Central Europe, southwards to North Africa, and eastwards through the Crimea and Syria to the shores of the Sea of Aral in Central Asia, proves that the sea in which the deposit was accumulated was by no means of inconsiderable extent.

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[8] *Quart. Journ. Geol. Soc.*, vol. xvi. p. 107. 'Fossil reptilian eggs from the Gloucestershire Oolite,' by Professor BUCKMAN.

We see therefore that the modern deposits present such close resemblances to ancient strata as to leave no room for doubt that in studying the rocks of the crust we are dealing with deposits recording conditions similar in their broad features to those with which we are familiar on the earth's surface to-day. Not only is there a close similarity between the structure and general arrangement of individual deposits of ancient and of modern times, but the changes in lithological character exhibited by modern deposits as they are traced towards or away from the sources of sediment, are equally well marked in the rocks of the past. One example will suffice to illustrate this point. The Jurassic limestones of the west of England, made up of corals and shelly remains indicating deposition in clear water free from sediment, when traced north-eastwards are found in mid-England to become more and more sandy in character. Followed still further to the north and east these sandy beds begin to exhibit most interesting traces of estuarine conditions by the appearance in them of interbedded bands containing plant remains. These characters become more and more pronounced till in Yorkshire the whole of the Lower Jurassic series consists of sandstones with alternating bands of carbonaceous matter—true coal-seams—instead of coral limestones as in Gloucestershire. The beds thus traced laterally into one another were undoubtedly deposited at the same time in different parts of the same sea. And the change in lithological character obviously indicates that the land from which the sedimentary material was transported into the Jurassic sea, lay to the north-east. The estuarine series of Yorkshire were certainly formed not far from shore off the mouth of a great river, while the coral limestones of Gloucestershire were accumulated in clear water more remote from land. Traced into Scotland these estuarine characters become still more marked. Jurassic strata are found both on the east and west coasts of Scotland. Good sections occur in Sutherlandshire, especially at Brora, as well as in Rosshire and Cromarty, and they also occur beneath the basalt sheets of Eigg, Skye, Raasay, and other western islands. They consist in the main of estuarine sandstones and shales containing beds of coal, with occasional bands of shelly limestones[9].

Similar changes may be detected in tracing even so markedly marine a deposit as the Chalk towards the north. Although but few traces of Cretaceous rocks have been recorded in Scotland, there is good reason for supposing that beds of Cretaceous age once extended over a large part of the country. Chalk flints with transported masses of Greensand occur largely in the drifts of north-east Scotland, and pebbly beds of flint, sometimes of considerable thickness, occur under the basalts of the west. The Cretaceous beds of Scotland, in the few spots where they have been detected *in situ*, e. g. Morven in Argyllshire and the Isle of Mull, instead of being pure chalk as in South England, consist of estuarine clays, sandstones, and thin seams of coal, with a band of genuine chalk about ten feet in thickness, the whole series being less than 200 feet. Obviously the Cretaceous land could not have been far off; indeed there can be little doubt that the Highlands formed part of it, for these interesting strata sometimes pass into coarse conglomerates, indicating the presence of the shore-line which bounded the Chalk sea.

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[9] *Quart. Jour. Geol. Soc.* vol. xxix. 'The Secondary Rocks of Scotland,' by J. W. JUDD, F.R.S.

The Organically-formed rocks due to plant remains find their most perfect representative in the coal of the Carboniferous series. It is a mistake to suppose that coal is confined to the Carboniferous formation. Examples have already been given of British coals of Jurassic and Cretaceous age. In other parts of the world coal is worked not only in Mesozoic but also in Tertiary beds, indeed there is hardly a geological formation which has not in some part of the world representatives containing accumulations of plant remains forming fossil fuel. In the peat of our own country, the cypress swamps of America, and the vegetable accumulations in the virgin forests of tropical countries, we have examples of modern deposits of plant remains with which the coals of the past may be compared.

The Chemically-formed rocks form so small a part of the crust that it is unnecessary to dwell further upon them than merely to point out that we find the analogues of the salt beds of the Trias in salt deposits which are at present forming in inland seas, like the Caspian, and in lagoons on the coasts of tropical countries.

TABLE III.

Classification of Rocks according to Mode of Origin.

I. Aqueous, Sedimentary or Stratified Rocks (due to the action of the External Agencies).	(*a*) Mechanically-formed.	Arenaceous, *e.g. Conglomerate Sandstone, &c.*
		Argillaceous, *e.g. Clay, Shale, Marl, &c.*
	(*b*) Organically-formed.	of Animal remains, *e.g. Limestone.*
		of Plant remains, *e.g. Coal, Peat, &c.*
	(*c*) Chemically-formed.	By deposition from solution in water, *e.g. Travertine, Stalagmite, Rock-salt, &c.*
II. Igneous Rocks (due to the action of the Internal Agencies).	(*a*) Volcanic.—Those which reached the surface, and in some cases flowed as lavas, *e.g. Basalt.*	
	(*b*) Plutonic.—Those which consolidated slowly under pressure at a depth below the surface, *e.g. Granite.*	
III. Crystalline Schists, and other Metamorphic Rocks of various origins.	The various schistose rocks, *e.g. Mica-schist, Hornblende-schist, Gneiss, &c.*	

Both Aqueous and Igneous rocks may undergo metamorphic changes, without entirely losing their original mineral texture, *e.g. Sandstone* altered into *Quartzite, Limestone* into *Statuary Marble,* and certain igneous rocks into *Serpentine.*

CHAPTER XIV.

THE IGNEOUS ROCKS AND VOLCANIC ACTION IN PAST TIMES.

AMONGST the rocks that constitute the crust of the earth, abundant examples of the Igneous group are also found, presenting among them all the various characteristics described in Chapters X and XI. Great Britain, situated as it is on the seaward margin of a continental area, where it bounds a great ocean basin, occupies a position peculiarly favourable for active manifestations of subterranean energy. The records of the rocks show a remarkable succession of volcanic eruptions, of every known type, continued with alternating periods of repose throughout geological time. These periods of repose include not only short intervals when a temporary suspension of eruptions took place, as is exhibited by modern active volcanoes like Vesuvius and Etna; but they include also prolonged periods of complete cessation of volcanic activity over the whole British area, like that during the immense interval of time represented by the succession of Mesozoic rocks.

It is profoundly interesting to find, in studying igneous rocks, that all the characters exhibited by the varieties of volcanic ejectamenta at the present day may be paralleled in the products of subterranean action in past times. Among the most ancient rocks of Great Britain are the granitoid Archæan rocks such as the fundamental gneiss of N.W. Scotland, and although they include no scoriæ or volcanic ash indicating action at the surface, there is reason to believe that they are in part, if not entirely, metamorphosed plutonic igneous rocks that probably once formed the deep-seated portions or roots of ancient volcanoes. For they present strong resemblances to similar rock masses in later formations 'which are connected as underground continuations with bedded lavas and tuffs that were erupted at the surface. Though no direct proof has yet been obtained of true volcanic ejections associated with the most ancient parts of the fundamental gneiss we may be reasonably certain that the rocks there visible consolidated from igneous fusion at some depth, and we may plausibly infer that they may have been actually connected with the discharge of volcanic materials at the surface[1].' More certain evidences of volcanic eruptions are afforded however by rocks of pre-Cambrian age younger than these ancient gneisses. In North Wales, underneath the fossiliferous Cambrian strata, a great series of lavas occur (Dinorwig Rocks of Table II) succeeded by volcanic tuffs, ashes, and agglomerates (Bangor Rocks of Table II). They exhibit differences in the nature and coarseness of the material, which indicate unquestionably a succession of eruptions. Some of the bands consist of coarse massive agglomerates that must have been accumulated not far from volcanic vents. Other bands consist of fine stratified tuffs reaching a great thickness and made up of material which is obviously fine volcanic dust.

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[1] Presidential Address, Geological Society, Sir A. GEIKIE, 1891, pp. 33, 34.

Coming to later times the records are still more easily interpreted. Without going into detail, it may be pointed out that the manifestations of volcanic energy during the period of the deposition of the Arenig and Bala beds (Table II), so largely developed in North Wales and the Lake Country, led to the piling up of volcanic ejectamenta to a thickness of hundreds or even thousands of feet. In the Snowdon area beds 6,000 to 8,000 feet thick occur in the neighbourhood of the ancient vents from which the material was discharged. These enormous thicknesses, however, are exceeded in the Lake Country, where Mr. Ward considered the maximum to range from 12,000 to 15,000 feet. The materials forming this huge mass of strata consist entirely of lavas and ashes with no intercalation of ordinary sedimentary material except at the bottom and top. In this series of rocks volcanic agglomerates may be studied in examples beautifully dissected out by nature's scalpel. The surfaces of rock by exposure to weather have been so acted upon as completely to reveal the characteristic structure where little could be learnt from a clean-cut surface. The atmospheric agents of destruction have picked out the softer portions of the matrix enveloping the great angular masses of igneous rock forming the agglomerate, so as to display the structure of the mass as unmistakably as if the actual accumulation of the fragments on the flanks of the ancient volcano could have been witnessed.

Not only do masses of fragmentary volcanic materials of this kind occur, but true lava-flows are recognised exhibiting characteristic structures. One of the most striking and remarkable is flow-structure. 'It is not difficult to detect,' says Sir A. Geikie, 'from the manner in which the lenticles and strips of the flow-structure have been curled over and pushed onward what was the direction in which the lava was moving while still a viscous mass. By making a sufficient number of observations of this direction, it might in some places be possible to ascertain the quarter from which the several flows proceeded[2].' In lavas discharged during eruptions of a later date in Old Red Sandstone times, 'an undulating rope-like surface' has been observed similar to the well-known ropy structure of some of the Vesuvian lavas described in a previous chapter, while the top and bottom of each sheet of lava exhibits a 'strikingly slaggy aspect which here and there is exaggerated to such an extent that between the more solid and homogeneous parts of two consecutive flows an intermediate band occurs ten or twelve feet thick, made up of clinker-like lumps of slag, the interstices being filled in with hardened sand. In some cases these agglomeratic layers actually consist in part of ejected blocks, and the way in which many of the lavas have cooled in rugged scoriaceous surfaces is as conspicuous as on any modern *coulée*.'

The position of the volcanic vents from which the various fragmentary materials and lavas were discharged can in many cases be recognised. Even when the cone itself has disappeared under the destructive action of denuding agents, as is usually the case, the position of the old volcanic tube with its plug of consolidated igneous rock has in hundreds of instances been made out. Ancient volcanic necks of varying dimensions from a few feet in diameter to upwards of a mile, abound among the Old Red Sandstone and Carboniferous strata of Scotland. Along the flanks of the escarpment extending from Stirling to Dumbarton the remains of no fewer than fifty volcanic vents of Carboniferous times have been mapped in a distance of sixteen miles, and the coast of Fife also affords excellent examples (Fig. 36).

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[2] Presidential Address, Geological Society, 1891, p. 85.

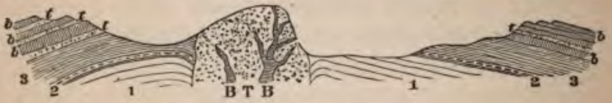

Fig. 36.—SECTION ACROSS VOLCANIC NECK, THE BINN OF BURNTISLAND, FIFE.

(After Geikie.)

1 Sandstone; 2 Limestone; 3 Shale; *bb* Interstratified basalts; *tt* Bedded tuffs; T Tuff of the great neck of the Binn; B Basalt veins.

Even when they are concealed by newer deposits we may often infer their position by an increase in the thickness of the volcanic accumulations as we approach the old centre of eruption, as well as by an increasing preponderance of agglomerates and tuffs. Traced in the opposite direction these volcanic ejectamenta thin away and disappear.

There is conclusive evidence of variations in the character of eruptions in different parts of the same area and of a shifting of the centres of eruption along definite lines—features which we have seen to be displayed in the volcanic district of Naples and elsewhere at the present day. An example of this is found in North Wales, where, during the eruptions of the Bala period in Carnarvonshire and Merionethshire, eruptions were also taking place in Anglesea. The Anglesea volcanoes, where the last efforts of the subterranean forces in Wales were manifested, differed from those of the South in that the ejectamenta from them were, as far as we know, entirely of fragmentary materials without any flow of lava. 'While the Carnarvonshire volcanoes were pouring forth their volumes of felsitic lava, and piling them up for thousands of feet on the sea-floor, the little northern Anglesea vents, not more than some five and twenty miles away, threw out only stones and dust, but continued their intermittent explosions until they had strewn the sea-bottom with detritus to a depth of many hundred feet[3].' The further fact that volcanic material appears in somewhat earlier beds in Carnarvonshire, and continues into later and still later beds as we proceed towards Anglesea, seems to show that there was a shifting of the centres of eruption from south to north in the way we see exemplified in regions of modern volcanic action.

Reference has already been made to the immense mass of ejected material piled up by volcanic action in Wales and the Lake District. In somewhat later times during the deposition of the Old Red Sandstone and Carboniferous series, masses not much less extensive were accumulated in central and southern Scotland. Lava-flows of immense extent and thickness may be traced in the Pentland Hills, some of them extending for sixteen miles. During the Carboniferous period lavas were poured out over an area of more than 2,000 square miles, and accumulated in successive sheets to a thickness in some parts of 1500 feet.

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[3] Presidential Address, Geological Society, 1891, p. 100.

In addition to these flows intrusive sheets of similar igneous rock frequently occur thrust in between the sedimentary members of the Carboniferous series. These intrusive sheets may without difficulty be distinguished from the interbedded lava-flows, not only by the absence of that scoriaceous surface which characterises the flows that have poured out at the surface, but also by the fact that they frequently cut across the sedimentary beds in an adjoining area in the manner shown in Fig. 37.

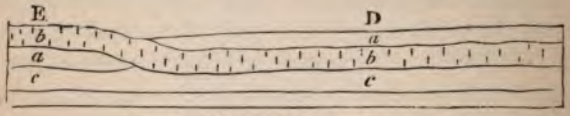

Fig. 37.—INTRUSIVE LAVA SHEET.

a c Carboniferous beds. *b* Lava sheet intruded and cutting across *a* at E.

Finally, after some minor manifestations in New Red Sandstone times, this long-continued volcanic action died out, not again to be revived until after the lapse of that immense period during which the Mesozoic rocks were deposited.

When volcanic action was next displayed early in the Tertiary period, there was no sign of abatement in the energy of the subterranean forces; indeed in some respects this later manifestation was unique. Dykes, consisting of fissures filled with igneous rock forced up from below, and cutting through and across the various beds, had frequently been formed among the Palæozoic rocks. Some of these fissures no doubt gave egress to molten lava which spread over the surface in sheets; but it was after the renewal of volcanic action in Tertiary times that the finest manifestations occurred of the type of volcanic action known as *fissure eruptions.* In our own country in the west of Scotland and in the north of Ireland there is a magnificent series of volcanic rocks of Tertiary age that seems to have been erupted from fissures, and similar rocks are displayed on a still grander scale in the Western Territories of North America, where there are vast tracts of country covered with sheets of basalt poured out as lava streams from great fissures without the formation of volcanic cones.

The following description of a visit to that district by a skilled observer gives an idea of the characteristic features and immense extent of these volcanic manifestations. 'Never shall I forget an afternoon in the Autumn of last year upon the great Snake River lava desert of Idaho. It was the last day of a journey of several hundred miles through the volcanic region of Yellowstone and Madison. We had been riding for two days over fields of basalt, level as lake bottoms among the valleys, and on the morning of the last day, after an interview with an armed party of Indians (it was only a few days before the disastrous expedition of Major Thornburgh, and, unknown to us, the surrounding tribes were already in a ferment), we emerged from the mountains upon the great sea of black lava which seems to stretch illimitably westwards. With minds keenly excited by the incidents of the journey, we rode for hours by the side of that apparently boundless plain. Here and there a trachytic spur projected from the hills, succeeded now and then by a valley up which the black flood of lava would stretch away into the high grounds. It was as if the great plain had been filled with molten rock which had kept its level and wound in and out along the bays and promontories of the mountain-slopes as a sheet of water would have done. Copious springs and streams which issue from the mountains are soon lost under the arid basalt. The Snake River itself, however, has cut out a deep gorge through the basalt down into the trachytic lavas underneath, but winds through the desert without watering it. The precipitous walls of the cañon show that the plain is covered by a succession of parallel sheets of basalt to a depth of several hundred feet. Here and there I was told, streams that had crossed from the hills and flowed underneath the lava-desert issue at the base of the cañon-walls, and swell the Snake River on its way to the Pacific[1].'

The resemblance between the horizontal basalt sheets of this region and the sheets of the same rock that stretch over great tracts of Scotland and North Ireland, offers strong presumptive evidence that the latter also are a product of the same type of eruption and have been emitted from fissures, rather than from volcanic craters of the ordinary type.

The origin and meaning of the vast number of dykes in North Britain filled with basalt have long been subjects of discussion amongst geologists. These dykes may be traced over an extent of country not less than 40,000 square miles, from Yorkshire and Donegal on the south away to the Orkney Islands on the north, and some of them are of extraordinary length. Their uniformity of trend is also remarkable. They run in a north-westerly or westerly direction, in long straight courses, sometimes for 60, 70, or even 100 miles. They cut across rocks of most diverse character and geological age, and that usually without any vertical displacement of the sides.

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[1] *Geological Sketches at Home and Abroad*, Sir A. GEIKIE, p. 278. Macmillan & Co.

The results of recent research leave little room for doubt that many of these basalt dykes were the fissures through which the great floods of lava, the denuded remains of which are still prominent on the west coast of Scotland and in North Ireland, were poured out in Tertiary times. Through these fissures and the various vents, some of which have been recognised, molten lava of the basic type welled up from below and covered wide tracts of country with successive sheets of basalt, attaining sometimes a thickness of over 3000 feet.

'The rise of molten rock in thousands of fissures over so wide a region is to my mind by far the most wonderful feature in the history of volcanic action in Britain. The great plateau of basalt and the mountainous bosses of rock by which they have been disrupted are undoubtedly the most obvious memorials of Tertiary volcanoes. But after all, they are merely fragments restricted to a limited district. The dykes, however, reveal to us the extraordinary fact that at a period so recent as older Tertiary time there lay underneath the area of Britain a reservoir or series of reservoirs of lava, the united extent of which must have exceeded 40,000 square miles.' These are the words in which the Director-General of the Geological Survey has recorded the impression made upon his mind by these magnificent and stupendous volcanic phenomena.

That long intervals of time separated these successive outpourings is indicated by the traces of ancient soils with layers of plant remains that frequently occur between two sheets. This fact, also, taken with the absence of marine fossils, indicates that the eruptions were subaërial. There is good reason for believing that some of the dykes never reached the surface, the lava which rose in them being forced between the partings of the adjacent and overlying strata to form intrusive sheets or sills.

In treating of the additions made to the land by subterranean energy it would be a mistake to neglect the effect of such geological action as that just referred to. The intrusion of these masses of lava had practically the effect of an addition to the land, for it must have resulted in an upheaval of the surface in the manner so well illustrated in the laccolites of the interesting district admirably described by Mr. G. K. Gilbert of the United States Geological Survey [5].

In Southern Utah, on the right bank of the Colorado river, is a wild and rugged desert region, deeply carved into cañons, from which rise a group of mountains called the Henry Mountains. Of this group the highest, Mount Ellen, is 11,250 feet above sea-level, and about 5000 feet above the plateau; while Mount Holmes, the lowest of the group, rises only about 7750 feet above the level of the sea. The surface rocks of the district belong in the main to the Cretaceous group. The study of this group of mountains has shown that each is a mass of igneous rock intruded into the sedimentary beds that originally lay horizontally over the area. To these igneous masses Mr. Gilbert has given the name of *laccolites* (λάκκος *cistern*, λίθος *stone*).

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[5] *Report on the Geology of the Henry Mountains* (U.S. Geog. and ~~l. Survey), by G. K. GILBERT.

The relation of a laccolite to an ordinary volcanic mountain will be readily grasped by a comparison of Figs. 38 and 39. In the case of a volcano the sub-

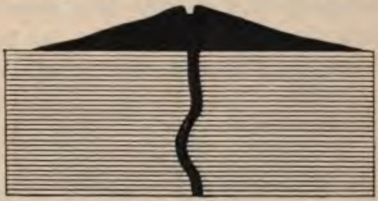

Fig. 38.—IDEAL CROSS SECTION OF A MOUNTAIN OF ERUPTION. (After G. K. Gilbert.)

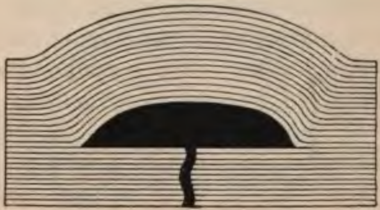

Fig. 39.—IDEAL CROSS SECTION OF A LACCOLITE, SHOWING THE ARCHING OF THE OVERLYING STRATA. (After G. K. Gilbert.)

terranean matter passing from below upwards through a fissure in the crust, is accumulated upon the surface to form a volcanic cone. In the case of the laccolite the fissure by which the molten lava ascends, instead of being continued to the surface, stops at a lower horizon, and the lava insinuates itself between two adjacent strata, lifting the overlying stratum and accumulating as it were in a chamber to form the core of the elevated dome. The strata uplifted and over-arching in this way have, under the destructive action of the agents of erosion, in large part disappeared, and each of the mountains of this group now consists of a mass of igneous rock originally the core of the laccolite, but now exposed and carved into rugged outlines by atmospheric agents.

A comparison of Plates II and III will make clear at a glance the nature of the changes produced in the form and contour of the country, by the differential action of the erosive agents upon the uplifted easily-destroyed sedimentary rocks and the more resisting igneous cores. Plate II gives an ideal representation of the country after the laccolites had been intruded; but before denudation had taken place. The 'Blue Gate Sandstone,' one of the upper members of the Cretaceous series, forms the surface of the ground which rises over each laccolite into a great dome or boss. Plate III represents the same district as it appears to-day after ages of denudation. From each boss the sedimentary rock has been removed more or less completely by the agents of erosion, exposing the igneous core of the laccolite which forms the main mass of the mountain. These cores dissected and laid bare by the scalpel of nature display great variety in their exposure. Mr. Gilbert describes how in one place arching strata only may be seen; in another arching strata crossed by a few dykes; in a third a portion of the laccolite itself bared so as to exhibit a natural section. Elsewhere the overlying sedimentary rocks have been removed entirely and the laccolite stands free in its original form, while at another spot the igneous rock itself has been attacked by the agents of erosion, and its outline changed. In Scotland some remarkable intrusions of coarsely crystalline basic rock—*gabbro*—of Tertiary age occur, which appear to be laccolites similar to those just described but somewhat older[6].

Thus it appears that while the 'elevation theory' of Von Buch and De Beaumont referred to in an earlier chapter, in the crude form in which it was put forward, was untenable, it undoubtedly contained a germ of truth. For although ordinary volcanic cones are not due to an upheaval of the ground—a blowing up as it were of a bubble in the crust—yet these recent geological investigations have revealed, as we have seen, the existence of mountain masses of igneous rocks the result of an elevation of the ground due to the forcing up of molten material from below.

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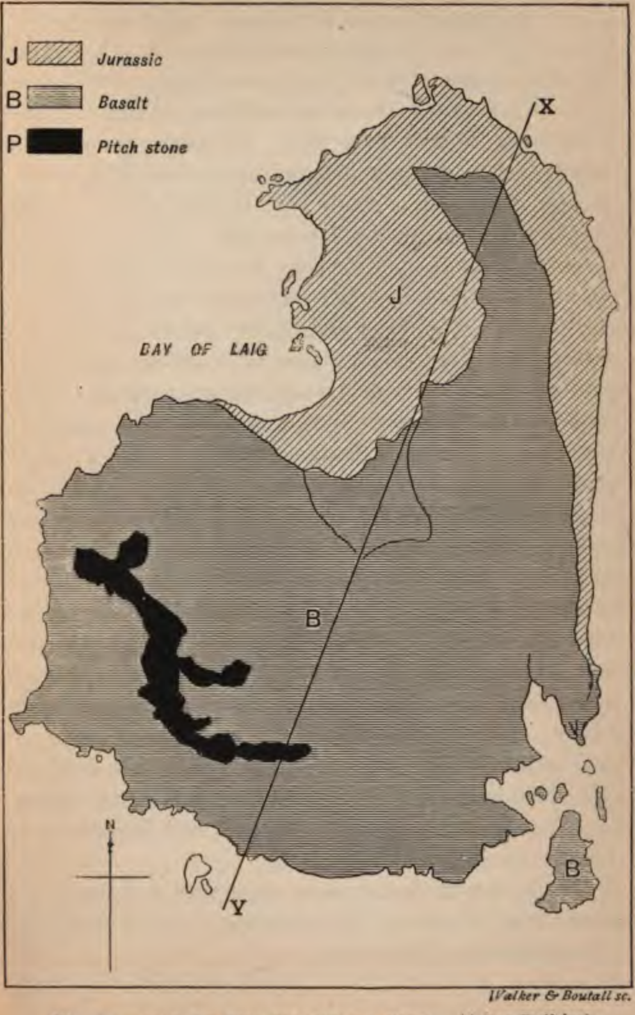
[6] *Transactions of the Royal Society of Edinburgh*, Sir A. GEIKIE, vol. xxxv. p. 142.

CHAPTER XV.

THE IGNEOUS ROCKS AND VOLCANIC ACTION IN PAST TIMES (*continued*).

THE influence of Tertiary volcanic action on parts of the British Isles has been strongly marked. The structure and characteristic scenic features of the western coast of Scotland, with the adjacent islands, are largely traceable to the stupendous manifestation of subterranean energy in Tertiary times. In order fully to realize the magnitude and importance of this action and to gain some idea of the vast period which has elapsed since the volcanic forces became dormant, it will be interesting and advantageous to describe in some detail one district, and no more striking example could be chosen than the Island of Eigg, off the west coast of Scotland. This island is five miles long, from a mile and a half to three miles broad, and reaches an altitude on the Scùir of Eigg, its highest point, of from 1200 to 1300 feet above sea-level. On approaching the island from the South, its distinguishing feature is seen to be a long, steep hill-ridge, terminating at both ends in a precipitous slope. The general structure of the island is shown on the map, Fig. 40.

Broadly speaking, the rocks of which the island is made



Walker & Boutall sc.

Fig. 40.—MAP OF THE ISLAND OF EIGG. (After Geikie.)
Pitchstone ridge forming the Scùir coloured black.

up may be grouped under three heads. The main part of the surface forms a basalt plateau (Figs. 40 & 41), consisting of a succession of old lava-flows, varying in thickness from a few feet to 50 or 60 feet each, and making together a thickness of over 1100 feet. Traversing these basalt sheets, various dykes, veins, and intrusions occur, which, as they form but a small part of the whole, are for simplicity's sake omitted from the map. That the sheets forming this plateau were streams of lava poured out at the surface, is sufficiently shown by the structure of the rock. The upper and under surfaces of successive sheets, like those of lava-flows of Vesuvius, and other modern volcanoes, have a rough, slaggy character in contrast with the more crystalline interior portion. Again, as affording still more striking evidence, layers of baked earthy material—old surface soils—containing plant remains, not infrequently occur between the sheets. They call up before the mind a picture of the old conditions when the surface of the lava, in the long interval between successive eruptions, became decomposed into soil that supported vegetation, which a later flow covered and hermetically sealed up, preserving from destruction an interesting record of an order of things long passed away.

Cropping up from underneath the basalt at the northern end of the island is a group of sedimentary rocks consisting of a series of fossiliferous clays, and limestones of Jurassic age.

Finally, the third and most prominent rock from the scenic point of view, is the pitchstone, which forms the hill ridge of the Scùir of Eigg.

The geological structure of the island and the relations of these various rocks to one another will be clearly apprehended from the section (Fig. 41) which represents what would be seen if the island could be cut into two parts vertically along a line a little to the east of X Y, and the eastern portion removed. The section shows that the basaltic plateau is lowest in the middle of the island, and rises towards the north and south, reaching its highest point on the south, where it is capped by the pitchstone ridge of the Scùir rising above the plateau 300 feet on one side and 400 on the other, in the way shown in Fig. 42. The total length of this ridge is two and a quarter miles, and its breadth varies between 350 and 320 feet. It will be noticed that two minor arms project from the ridge on the north-eastern side in a highly suggestive way. The characteristic physical structure of the Scùir standing out as a bold steep-sided ridge, so scenically different from the basaltic plateau upon which it rests, is paralleled by a striking difference in the mineralogical structure and chemical composition of the rocks. The pitchstone (named from its superficial resemblance to pitch) with its interbedded bands of felstone porphyry composing the main mass of the ridge

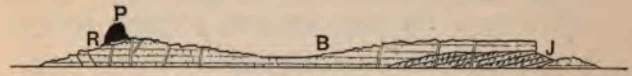


Fig. 41.—SECTION SHOWING THE GEOLOGICAL STRUCTURE OF THE ISLAND OF EIGG.

(After Geikie.)

P Pitchstone ridge; B Basalt plateau; R Old river gravel; J Jurassic clays, shales and limestones.

of the Scùir, is a volcanic rock of the Acid group, rich in silica, and of dark colour, differing from the basalt of the plateau in appearance, composition and power of resisting atmospheric disintegration.

The form of the ridge led early geologists to conclude that it was part of a great dyke or intrusive mass which had been thrust through older rocks. That view however is shown to be untenable by the bedded character

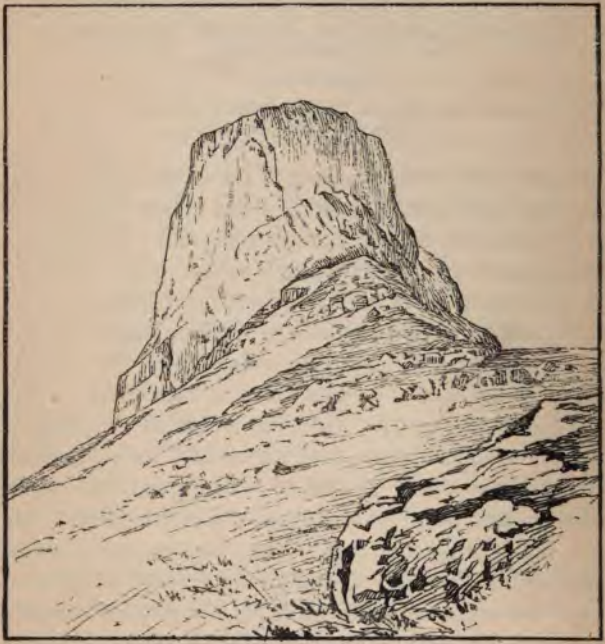


Fig. 42.—SCÙIR OF EIGG.

of the pitchstone, while the relation of the mass to the underlying basaltic rock renders it clear that the Scùir is a portion of a lava-flow of posterior date to the basalt. That being so, the question at once suggests itself, how could a molten mass form a steep-sided hill ridge like the Scùir? It could not have been poured out as it now stands, for it would necessarily have flowed down on either side. Obviously the conditions prevailing in the district at the time of the outflow of the pitchstone lava must have been very different from those of to-day. What then were the conditions? A careful study of the junction of the pitchstone with the basalt has suggested the answer by showing that the surface of the basalt, upon which the pitchstone rests, is an eroded surface. This is not all, for at several points along the ridge, and especially at the extreme ends, both north-west and south-east, a bed of fragmentary material has been noted, between the pitchstone and the basalt. This bed consists of angular, sub-angular, and rounded fragments and pebbles of basalt, red and white sandstones, and other rocks, together with pieces of coniferous wood. The character of the deposit and its position proves it to be an old river-gravel, and the whole story stands revealed. The Scùir of Eigg obviously marks the line of an ancient river valley. Turning again to the map (Fig. 40) we see that the very shape of the ridge with its elegant S curve, suggests a river channel, the minor arms on the north-eastern side indicating the positions of tributary valleys at their junction with the main valley.

The succession of events must have been somewhat as follows—In early Tertiary times, after the eruptions that furnished the basaltic lava-flows had come to an end, a river carved for itself a channel through the rocks that formed the surface of the land area of which the Island of Eigg is a denuded fragment. From the relics of this ancient valley, preserved to us under the Scùir, we may learn whether the river flowed from the west or the east, and where it took its rise. The angle at which the tributaries meet the main stream, together with the fact that the old river-bed is higher at the east end of the Scùir than at the west, seems clearly to indicate that the flow of the river was towards the west, and that it emptied itself into the Atlantic. It must beyond question have taken its rise in the north and not the south, for the pebbles in this old river-gravel, are, many of them, composed of rocks that could only have been derived from the north or north-west, such as the red sandstones of the Cambrian of the Highlands, the quartzite and slates of Inverness-shire, and the white Jurassic sandstones of Skye and other parts of the north. That the country through which the river flowed was clothed with pine-forests, is certain from the fragments of coniferous wood preserved amongst the pebbles.

How long this condition of things prevailed we cannot tell, but it was long enough for the channel through the plateau to be eroded to a depth of at least 400 feet. Then came the rekindling of the volcanic fires, and the opening of a vent somewhere in the neighbourhood, from which a stream of pitchstone lava was poured out which ran into the river channel, just as slag from an iron furnace runs into the mould prepared for it. The valley was thus filled with igneous rock, which sealed up the pebbly bed with its fragments of drift-wood just as it stood. If a section could have been taken across it immediately after the pitchstone eruption, it would have presented some such appearance as that in Fig. 43. The

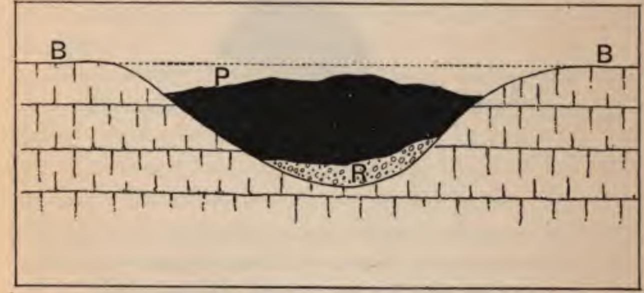


Fig. 43.—DIAGRAMMATIC SECTION OF THE OLD VALLEY THROUGH THE BASALT PLATEAU OF EIGG AFTER THE INFLOW OF THE PITCHSTONE LAVA.

P Pitchstone lava ; B Basalt plateau ; R River gravel.

volcanic fires again died away, and the last display of volcanic activity in the British area came to end. The agents of destruction—wind, rain, and frost—continued to make their unceasing attacks alike upon the basalt plateau and upon the pitchstone which had filled up the old river channel. The pitchstone being more resisting and less easily decomposed than the basalt, yielded more slowly to these destructive agencies, and has endured while the slopes of the ancient valley and the surface of the plateau were gradually lowered, until the condition of things shown in Fig. 44 has been reached, and what was once a valley forming the lowest part of the region, stands up as the summit of the water-shed [1].

The contemplation of this ancient monument of Nature's own building, that indicates alike the action of the constructive internal forces and the destructive external forces, cannot fail to impress the mind with the vast periods of time with which the geologist has to deal. The destruction of the hundreds of feet of basalt rock by the action of the atmospheric and aqueous agents of which we have evidence in the phenomena just described, has all taken place since late in the Tertiary period. When we reflect how slowly destruction goes on from day to day and year to year we begin to realize the enormous lapse of time represented by such relics of denudation as these on the islands and mainland of the West of Scotland.

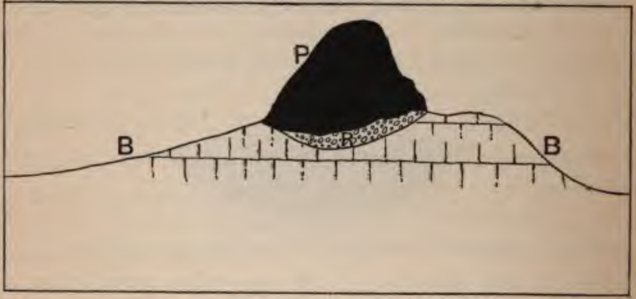


Fig. 44.—DIAGRAMMATIC SECTION SHOWING PRESENT STRUCTURE OF THE SCÙIR OF EIGG AFTER DENUDATION.
P Pitchstone; B Basalt; R Old river-gravel.

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[1] *Quart. Jour. Geol. Soc.* vol. xxvii. 'On the Tertiary Volcanic Rocks,' by Sir A. GEIKIE.

Not less impressive are these Tertiary volcanic rocks from the point of view of construction. No one can follow the detailed unfolding of the history of volcanic action in Palæozoic times, and its revival on a stupendous scale in Tertiary times without realising that materials extruded from the interior have played a far larger part in building up the land than we have been accustomed to suppose.

The account of volcanic phenomena here given has been necessarily subordinated to the ground purpose of this volume, and many interesting aspects of the subject have therefore been unavoidably passed by unnoticed. During recent years Vulcanological questions have attracted increasing attention, and valuable additions to our knowledge have been made, but much remains yet to be done in this department. Recent geological research, with the improved methods of investigation placed within our reach by the application of microscopical investigation to Petrology, has also thrown much light on many difficult petrographical problems, and has already led to the abandonment of many old ideas. Doubtless with the advance of knowledge other long-cherished theories may not improbably also have to go.

CHAPTER XVI.

THE EVOLUTION OF THE BRITISH ISLANDS.

WE have now seen the nature of the various rocks composing the land. It remains to consider in what way the British land-area has been built up and developed, what has been the nature of the evolution.

The various colours and tints on the geological map of Great Britain (Plate VIII) represent groups or subdivisions of rocks of different geological ages. To a non-geological eye the distribution of the colours may appear so irregular and disorderly, as almost to suggest that the contents of a paint-box had been used at random in making the map. The only obvious suggestion of order is found in the succession from west to east of strips of pink, brown, yellow, and green, stretching from Yorkshire to Dorsetshire; yet every strip and patch of colour is so placed upon the map as to cover the parts of the country where the rocks represented by that colour are known to appear at the surface. It is clear that Great Britain is, geologically speaking, built up of beds of great diversity of age.

If we compare the map showing the physical configuration of the British Islands (Plate IV) with the Geological Map (Plate VIII), we shall be struck with the fact that the mountainous regions of the west and north are the parts where the older rocks appear at the surface. We observe also that in passing from west to east, say from North Wales to the coast of Norfolk, we pass successively in regular order, over the outcrops of newer and newer beds, which form bands having a south-west to north-east direction. If we imagine England cut into two, along a line from Snowdon to Harwich, and the southern portion removed, so as to show, in a vertical section, the relations of these beds to one another, we should have presented to our view substantially what is shown in the Section. (Plate VIII.)

The Cambrian and Silurian rocks that form the high lands of Wales, themselves resting unconformably on more ancient pre-Cambrian rocks, are continued underneath the newer strata of England, and form a kind of platform on which these newer beds have been laid down. That the older rocks do so extend eastwards is proved by deep borings made in different parts of the country, during mining operations or for the purpose of obtaining water. In the South-Staffordshire coalfield, for instance, borings through the Coal-measures have come down upon upper Silurian and Cambrian rocks; near Northampton borings reached strata at a depth of 699 feet which were certainly Carboniferous, and others at 950 feet, which there is reason to believe were Old Red Sandstone; still further east Silurian rocks were reached in a boring through the Cretaceous beds at Ware at a depth of 800 feet; in London and the neighbourhood, Devonian beds have been reached at a depth of 1148 feet, and at Harwich the Lower Carboniferous at about 1000 feet, while, as the most recent and interesting example of all, we have the finding of coal at a depth of about 1100 feet at Dover. We are therefore unquestionably entitled to infer that there is a continuous underground platform of older rocks connecting the Palæozoic beds discovered in the borings in the east of England with the similar beds that rise to the surface in Wales.

The newer beds, it will be noticed, succeed one another in regular order, resting one upon the other, and so indicating the mode of growth of the area. Evidently England has grown from west towards east by the successive addition of layers of newer and newer strata. Each of these deposits is an ancient sea-bed or lake-bed, and the materials of which it is composed must have been derived from some neighbouring land washed by the waters of the sea in which the deposition took place. The arrangement of the strata dipping in regular order one beneath the other as shown by the Section, and the changes in their lithological character and thickness as they are traced from south-west to north-east, prove that the older rocks of the west and north formed part of the mountainous land-area, the destruction of which by the agents of denudation furnished the materials that formed the newer deposits. It is only by a detailed study of the several strata that the exact boundaries and extent of the land at each successive period can be made out. The evidence however is at present so incomplete that this can only be done in an inadequate and imperfect way, but every year is adding fresh material and rendering the unfolding of the geological history of the British area more and more complete.

In order to illustrate the method by which such an investigation as is here indicated may be carried out, let us take the Carboniferous series, and work out in detail the restoration of the physical features of the British area during the deposition of those beds. We consider first the beds as they may be observed in any typical district, with the view of seeing what can be learnt as to the conditions under which they were laid down in that particular place. Turning to the Table of Strata (Table II), we see that the Carboniferous group is divisible into three main sub-divisions, the Carboniferous, or Mountain Limestone, the Millstone Grit, and the Coal-measures. In the middle of the Old Red Sandstone beds of South Wales there are indications of an *unconformability* which is well marked in the same beds in Scotland. The lower Old Red are therefore here classified with the upper Silurian, and the upper Old Red with the Carboniferous. Tracing the upper Old Red from Brecknockshire, where they are well developed, into Glamorganshire, they are found to pass up *conformably* into a series of dark earthy shales, occasionally interstratified with yellowish sandstones, with always thin flaggy limestones in the upper part forming the Lower Limestone Shale from 300 to 500 feet thick, containing characteristic Carboniferous fossils. This impure limestone shale graduates up into the massive pure Carboniferous Limestone, composed of organic remains, and about 1000 feet in thickness. Upon this rests conformably the Millstone Grit, a series of hard sandstones and grits, forming the middle member of the Carboniferous series, and finally, overlying the grit, are the Coal-measures, an enormous series of beds of shale, sandstone, ironstone, and seams of coal, forming a thickness of from 5000 to 12,000 feet.

The regular and significant changes in lithological character successively shown by these subdivisions indicate corresponding changes in physical conditions. They afford evidence that the land area of Old Red Sandstone times, with its great lakes, in which the red beds were laid down, underwent depression, until the sea made its way into the lacustrine region, bringing in the marine fossils entombed in the Lower Limestone Shale. As the subsidence continued the water became deeper, more remote from the sources of sediment, and consequently clearer and more favourable for the accumulation of organic remains. Thus the upper part of the limestone shale becomes more and more calcareous by the appearance of the thin flaggy limestones. This subsidence, continued still further, introduced conditions as regards remoteness from sources of sediment and consequent clearness of water, favourable for the accumulation of the thick pure Carboniferous Limestone. An immense period of time must have elapsed to allow of the formation of the hundreds of feet of this rock, consisting of organic remains quietly accumulated in the clear waters of the Carboniferous sea. Then further changes occurred, and the sandstones of the Millstone Grit were laid down over the Limestone. In certain parts of England an intermediate series of shale occurs known as the Yoredale rocks, showing a gradual transition from the clear water conditions of the Carboniferous Limestone to the condition of a sea charged with arenaceous sediment, in which the Mill-stone Grit was laid down. Even in South Wales the Carboniferous Limestone shows in its topmost bands alternations of dark shales with bands of limestone which may fairly be taken to represent the Yoredale series[1].

The sandstones of the Millstone Grit imply shallower water and the greater proximity of a land area, from which the sandy material was derived. They are very coarse in character and consist of angular grains but slightly worn and often of large size. They are also remarkably persistent over large areas. These characters suggest a considerable upheaval of the area during the deposition of the Millstone Grit. The shallow-water conditions were continued until the Coal-measures were deposited, and although it is certain that the Coal-measures were laid down on a subsiding sea-bed, the subsidence was so gradual that silting up by deposition kept pace with it, so that the water remained shallow. These beds furnish proof of the conversion of the sea-bed into extensive swampy lands, subject to frequent oscillations of level; for the beds of coal, which are accumulations of vegetable remains undoubtedly formed under terrestrial conditions, alternate with sandstones deposited in water. Each seam of coal usually rests upon an underclay, in which curious woody fragments—*Stigmaria*—are frequently found, the nature of which was not at first understood. They are now known to be the roots, or possibly, the rhizomes of the lycopodiaceous plant *Sigillaria*.

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[1] *The Coalfields of Great Britain.* By E. Hull, LL.D. p. 94.

Specimens of the stems of *Sigillaria* have been found standing in the underclay, and united below with *Stigmaria*. There can be little question that the underclays are old surface soils in which the Carboniferous trees grew, and they indicate therefore the elevation of the sea-bed into land, upon which the Carboniferous forests flourished for generations, while the accumulation of vegetable material was taking place. Much interesting light has been thrown by recent research upon the conditions under which these Coal-beds were formed.

Coal may be divided into two main varieties: the *bituminous* and the *anthracitic*, which present very different appearances both in hand specimens and in thin microscopic sections. Attention was prominently drawn by Professor Huxley some years ago to the structure of the bituminous variety[2]. It is usually a hard shiny brittle coal, burning with a bright flame, and when examined under the microscope in thin sections, is seen to consist of a dark ground mass, containing multitudes of curious discs of a yellowish brown colour, with a diameter of about $\frac{1}{20}$ of an inch. On one side of these discs may be discerned three linear marks radiating from the centre. Sections cut in various directions show that these bodies are tiny flattened bags, and that the linear markings are clefts in their sac walls. The sacs are usually full of smaller irregular rounded objects, not more than $\frac{1}{700}$ of an inch in diameter (Fig. 45, A, B). At first sight the vegetable character of these coals is not apparent, and it is to the late Professor Morris that we owe the first suggestion that the sacs, with their contents, are analogous to the sporangia and spores of plants allied to the living club-moss. Many years later the matter was definitely settled by the discovery of these sacs attached to the fossilised cone from which they were produced. The cone was described by Mr. Carruthers under the name of *Flemingitis gracilis*, as belonging to a tree allied to Lepidodendron, a gigantic ancient club-moss, common in the Coal-measures. These plants, unlike their degenerate modern representatives, the club-mosses, grew to tree-like proportions and formed great forests. Season after season the trees shed their spores in enormous quantities;

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[2] *Critiques and Addresses* (chapter On Coal). By T. H. Huxley, LL.D. Macmillan.

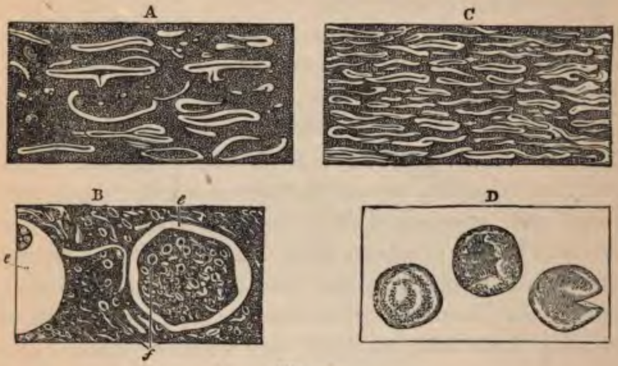

Fig. 45.

A. 'Better-bed' Coal from a portion unusually full of *Sporangia*, which are here shown in traverse section.

B. Same Coal section parallel with bedding; showing *Sporangia*, *e*, and *spores*, *f*; the latter (which are here represented somewhat too large) appear as bright rings enclosing a dark spot.

C. Australian 'White Coal' showing the *Sporangia* in traverse action.

D. External View of Sporangia separated from the 'white coal.'

All these figures are enlarged about 15 diameters.

The bodies here called *Sporangia* are by some persons considered to be *Macrospores*, and those called *Spores* to be *Microspores*.

these accumulated upon the ground, and with the remains of leaves, dead branches, and decayed trunks, formed beds of vegetable material that became converted into seams of coal by subsequent pressure of overlying strata deposited upon them.

We are fortunately able to point to comparatively modern vegetable deposits presenting the closest analogy with these bituminous coals. The lignites known as the 'White Coal' of New South Wales, and Tasmanite, a combustible material from the River Mersey on the north side of Tasmania, present in microscopical section precisely the appearance of bituminous coal. They are seen to consist of minute discs of a brownish colour, the discs being more or less circular bodies, somewhat thickened towards the circumference, and many of them having their surfaces raised into irregular folds. The double contour line, which the more perfect discs show, prove that they are really thick-walled sacs. Inside these sacs are numerous minute bodies, the general structure of which indicates that they are spores of some lycopodiaceous plant (Fig. 45 C. D.). The microscopic structure, and the mode of occurrence of this 'White Coal' and Tasmanite show that they are deposits closely allied to coal, and accumulated under similar conditions to the Coal-measures[3].

The closeness of the analogy between the conditions in Carboniferous times and those prevailing in the virgin forests of tropical countries, is still further emphasized by Principal Sir J. W. Dawson's interesting discoveries in the Coal-measures of Nova Scotia. He there found the remains of air-breathing creatures, snails, scorpions, centipedes, and Amphibia inside the trunks of Coal-measure trees. Frequently these trees are found standing erect in the soils in which they grew (Fig. 46). In other cases they lie fallen, their interiors having evidently rotted away while the trees stood, so that when they fell the shell of bark that remained was readily flattened by the pressure of the material accumulating upon it. In a recent communication to the Royal Society, Sir J. W. Dawson states that since 1851, when the first remains were obtained from these Nova Scotian beds, by Sir Charles Lyell and himself, they have afforded examples of twelve species of Amphibians, three land snails, eight millipedes, three scorpions, and an insect. These have all been extracted from Sigillarian trees. Many of the remains were in so fragmentary a condition as to render their determination a matter of difficulty. He suggests that they were probably little more than the

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[3] *Geological Magazine*, N.S. Decade II, vol. ii, p. 337.

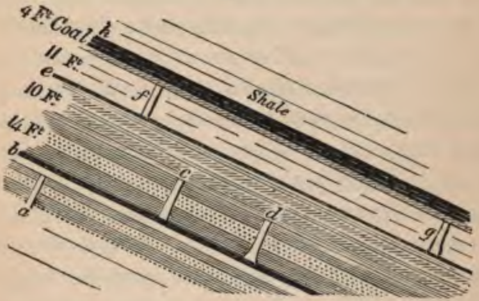

Fig. 46.—ERECT FOSSIL TREES *a*, *c*, *d*, *f*, *g*. COAL-MEASURES NOVA SCOTIA.

débris of the food of the Amphibians that lived for a time in these hollow stumps and devoured such smaller animals as were so unfortunate as to be imprisoned with them.

The spores and spore-cases revealed by the microscopical examination of the more bituminous varieties of English coal seem to occur only rarely in the coals of North America. Sir J. W. Dawson, who examined the American coals from this point of view, reported that indications of spores and spore-cases were rare, and that the poorer coals certainly consist principally of cubical tissues, with some true woody matter.

The second chief variety of coal—*Anthracite*—is bright, vitreous, black, and friable. It is probably bituminous coal which has been subjected to pressure and heat under the influence of which the volatile hydrocarbons have been expelled and the mass has approached the condition of graphite.

The facts above adduced afford conclusive evidence of the prevalence of terrestrial conditions during the formation of the vegetable accumulations that form the seams of coal. In some parts, beyond question, the land was flat and swampy, and the deposits of vegetable material were formed in shallow ponds and lagoons upon its surface, and were mingled with mud and other sedimentary material. In other parts, however, the land was at a sufficient elevation to be free from any incursions of sea-water. This is proved by the presence of underclays, the old soils upon which the coal-plants grew, and by the structure of the pure bituminous coals, made up almost entirely of spores that fell from the forest-trees growing upon the surface, without admixture of sedimentary substance. The curious discoveries already referred to of the remains of insects and other air-breathers in the decayed trunks prove that the terrestrial conditions under which the ancient forests flourished for generations, were very similar to those now prevailing in tropical countries.

At intervals oscillations of level certainly occurred, and a temporary subsidence would lead to the covering of the bed of vegetable matter with sandstone or shale, to be followed after an interval by an upheaval, introducing again land conditions, when another seam of coal was accumulated, to be succeeded by another subsidence and so on. Despite the local oscillations of upheaval and depression, there was on the whole a steady set downwards, so that between the beginning and the end of the Coal-measure period there must have been a subsidence of 10,000 to 12,000 feet to allow of the deposition of the thick series of sandstones, shales, and coal seams that constitute the Coal-measures, all formed under shallow-water or terrestrial conditions.

CHAPTER XVII.

THE EVOLUTION OF THE BRITISH ISLANDS (*continued*).

The Area in Carboniferous Times.

HAVING now learnt what may be gathered from a study of the lithological character of the several subdivisions of the Carboniferous Rocks, let us proceed to trace them from one region to another, and by observing the lithological changes which they undergo endeavour to restore the old distribution of land and water. The frontispiece is a map showing the distribution of land and water in the area of the British Isles in Lower Carboniferous Times. The mode of reasoning upon which the map has been constructed is as follows.

Starting from Derbyshire, where the Carboniferous Limestone is thick, massive, and pure, we find in tracing it towards the north-west and north that it begins to show significant alterations in character. In Yorkshire bands of shale appear, which further north become thicker, the limestone thinner, and interstratifications of beds of sandstone occur. Traced into Northumberland the limestone becomes still more impure, and in addition to shales and sandstones, thin seams of coal appear in it. Following the beds into Scotland these changes become still more pronounced, so that in the central valley of Scotland, instead of three well-marked subdivisions—Coal-measures, Millstone Grit, and pure Limestone, the whole series, 8000 or 9000 feet thick, consists from top to bottom of alternations of shales, sandstones, fire-clays, seams of coal and thin beds of limestone, the last being more frequent in the lower part of the series.

The broad features of the distribution of the Carboniferous series will be more clearly apprehended by a study of the maps Figs. 48 and 49. The method of representing the results adopted in constructing these maps was first suggested by Professor Hull in a paper read before the Geological Society on *Isodiametric Lines*[1] many years ago. As Professor Hull pointed out, we may regard all formations composed of sedimentary materials as exhibiting in cross-section a figure included by the arc of a curve and its chord (Fig. 47). The exact form of the figure will of course vary according to circumstances, but it will in every case taper towards the shore and towards the deep sea. The thickest portion of the deposit will not be exactly at the centre, but between the

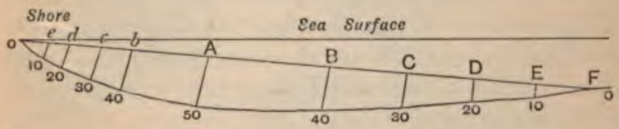

Fig. 47.—DIAGRAM REPRESENTING SECTION OF A FORMATION SHOWING ARRANGEMENT OF SEDIMENT ON THE SEA BED.

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[1] *Quart. Jour. Geol. Soc.* vol. xviii. p. 127. 'On Isodiametric Lines as a means of representing the distribution of sedimentary clay and sandy strata as distinguished from calcareous strata.' By E. HULL, LL.D.

centre and the shore. On each side of the line of greatest thickness, *A*, in Fig. 47, say fifty feet in thickness, it will be possible to mark points where the thickness is the same; for example, at *b*, on the shore side, and at *B*, on the sea side, the thickness is forty; at *c*, on the shore side, and at *C*, on the sea side, the thickness is thirty, and so on. Now, if upon a ground-plan of the area, where the deposit occurs, lines are drawn on the surface through all the points where the thickness is the same, they will obviously tend to form curves round the central point of greatest or least thickness. It will be seen that these lines form a sort of stratigraphical contour lines, but instead of representing equal altitudes they represent equal thicknesses. For these Professor Hull proposed the name *Isodiametric*, or, more shortly, *Isometric* lines. They are not intended, as he was careful to point out, to show the present or actual thickness of the strata, which may have been in part denuded, but the *original thickness before denudation*, and they may therefore be traced over areas where the strata have in part, or even wholly, been swept away.

On the map of England (Fig. 48) *Isometric* lines have been drawn so as to represent the distribution of the calcareous division of the Carboniferous rocks, i.e. the Carboniferous Limestone, and in Fig. 49 those showing the distribution of the sedimentary division of the same series, i. e. Yoredale Rocks, Millstone Grit, and Coal-measures.

Let us consider first Fig. 48, representing the distribution of the Carboniferous Limestone. We must imagine the limestone which had been removed by

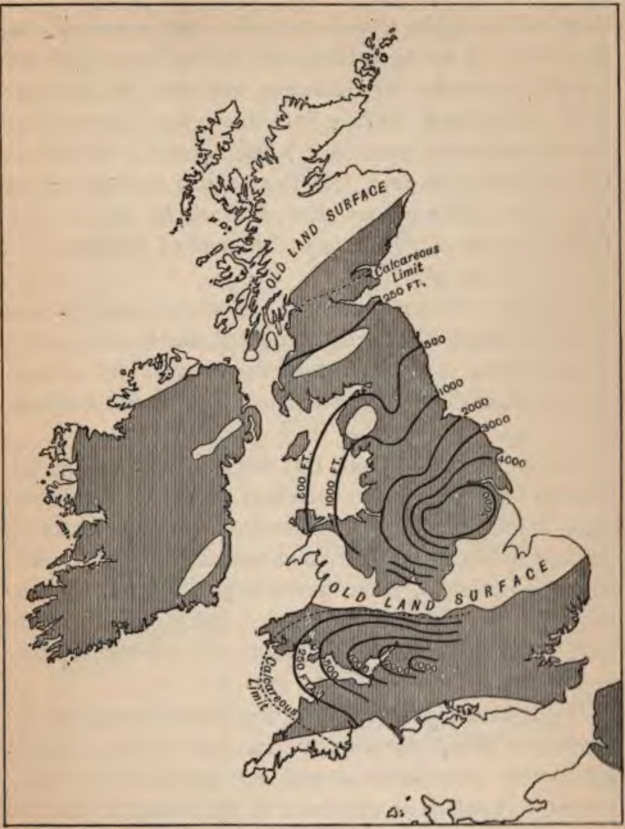

Fig. 48.—MAP SHOWING BY MEANS OF *ISOMETRIC* LINES THE DISTRIBUTION OF THE CALCAREOUS MEMBER OF THE CARBONIFEROUS, i.e. CARBONIFEROUS LIMESTONE, OVER GREAT BRITAIN.

(After Hull.)

The area over which the Coal-measures probably once extended is shaded.

denudation, again spread over the area where it was deposited; if we were then able by boring at different places to measure its thickness, and were to set those down on the map, drawing lines through all places where the thickness was equal, first a line through points where the thickness was 5000 feet, then a line through points where the thickness was 4000, similarly for 3000, 2000, and so on, we should have such a map of *isometric* lines as that in Fig. 48.

Dealing in like manner with the sedimentary division —the Yoredale Rocks, Millstone Grit, and Coal-measures —and laying down on a map the *isometric* lines representing their distribution, we should have what is shown in Fig. 49.

A comparison of these two maps shows that the calcareous and sedimentary members of the Carboniferous series thicken in opposite directions. The limestone is thickest in Derbyshire, and thins towards the north; while the sedimentary matter is thin in Derbyshire and thickens towards the north and north-west. Similarly in south-west England the limestone thins and the sedimentary members thicken towards the west.

It will be obvious what this progressive increase in the proportion of sedimentary material as the beds are traced northwards into Scotland and westwards from S. Wales means. It means an approach to the shores of the old land area whence the materials that form these deposits were derived. North of a line across mid-Scotland no Carboniferous beds are found, and there can be no question that the Highlands formed part of the ancient land. The old shore line may be traced by the occur-

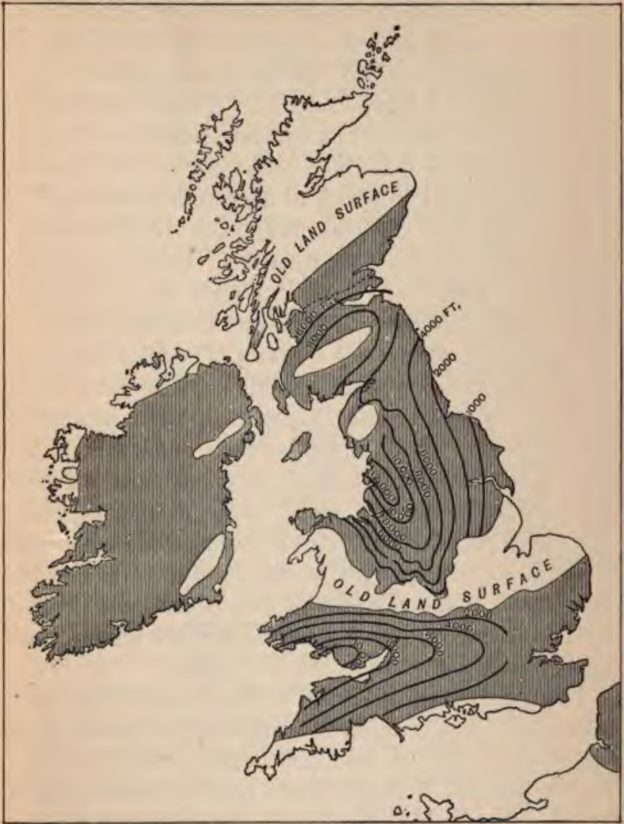

Fig. 49.—MAP SHOWING BY MEANS OF *ISOMETRIC* LINES THE DISTRIBUTION OF THE SEDIMENTARY MEMBERS OF THE CARBONIFEROUS, i. e. YOREDALES, MILLSTONE GRIT AND COAL-MEASURES OVER GREAT BRITAIN.

(After Hull.)

The area over which the Coal-measures probably once extended is shaded.

rence of a conglomerate at the base of the Carboniferous beds. In Lanarkshire the shingle of the Carboniferous beach rests upon the Old Red Sandstone, and to a great extent is derived from its waste. A conglomerate also surrounds the Cheviot Hills, composed of pebbles derived from the rocks of those hills, showing that the Cheviots must have formed an island in the Carboniferous sea.

Not only the Cheviots but parts of the mountainous lake country also formed an island, as similar evidence shows. The basement beds of the Carboniferous resting upon the Silurian and Cambrian rocks of Westmoreland form thick deposits of conglomerate and sandstone indicating shore conditions. The existence of land in this area is also suggested by the character of the Millstone Grit at Knaresborough, about sixty miles to the south-east of the Lake Country. It is made up of the detritus of granitic rocks, many of the fragments being large rounded pink felspar crystals, precisely similar to those so characteristic of the Shap granite of Westmoreland. If the material of this deposit was derived from Shap that area must have been above water undergoing denudation in Millstone Grit times.

The materials of which the Millstone Grit of Yorkshire is composed was certainly to a large extent derived from the waste of a granitic area, and Dr. Sorby has contended that the pebbles of granite which have occasionally been found in it resemble more closely the granites of Norway than any British variety. This renders it probable that the Scandinavian peninsula formed the Eastern boundary of the Lower Carboniferous Sea, and that view is confirmed by the direction of the planes of current bedding in these rocks which show that the materials came from the north-east [2].

Crossing over into Ireland we find the Carboniferous Limestone largely developed over the greater part of the country. As in England the limestone is pure in the central parts, and becomes more impure by admixture of sedimentary material as it is traced towards the north and north-west, indicating that the western portions of Donegal and Connemara formed, like the Highlands of Scotland, a part of the land area of Carboniferous times.

Turning again to Derbyshire and tracing the Limestone to the south we find a rapid thinning. Where it occurs on the northern margin of Charnwood Forest in Leicestershire, instead of being 4000 or 5000 feet thick, as in Derbyshire, only twenty miles distant, it is reduced to about forty feet. And it also becomes less pure with intercalations of thin sandy beds. Here again we have evidence of an approach to an old shore line, and there can be little doubt that the old rocks of Charnwood Forest formed land in this direction.

Let us now endeavour to trace the boundaries of this land which occupied central England in Lower Carboniferous times. At the outset we are certain that it was not of any great extent, because the thick and pure limestones of Derbyshire were deposited in clear water only a few miles to the north, showing that no large quantity of sediment was poured into the sea from the south as would have been the case if an extensive land area lay in that direction. Again, as we approach Charnwood Forest intercalated sandy beds appear in the Limestone which are so thin as to show that the rivers emptying themselves into the sea from the land of mid-England were tiny streams carrying but little sediment.

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[2] *Memoirs of the Geol. Survey.* 'Geology of the Yorkshire Coalfield,' by A. H. GREEN, M.A., and others, p. 23.

We are fortunately able, owing to the numerous natural sections and borings in the midlands, to fix with some exactitude the boundaries of this old land. At Coalbrook Dale in Shropshire the Carboniferous Limestone is thin, as it is at Charnwood Forest, and has a similar impure character indicating proximity to the old shore. A line between these two places will give approximately the direction of the Northern shore line of this old land of central England. In the South Staffordshire coalfield we have indications of its actual position, for borings have shown that the Carboniferous Limestone is entirely absent, and that the Coal-measures rest on an eroded surface of older rocks, at one place Silurian and at another Cambrian, while the Silurian rocks at Dudley, Walsall, and elsewhere in that coalfield rise from beneath the Carboniferous beds into hills, relics of the old land whose outlines we are endeavouring to trace. At one spot a most interesting trace of the ancient coast—a veritable old beach of the time—was met with in boring for coal on the southern margin of the coalfield. The condition of things is elucidated by Fig. 50. Borings in the northern part of this coalfield passed through a succession of coal-seams some of which are indicated by the letters *D*, *E*, *F*, down to the well-marked seam *G*, known as the 'Thick coal.' In 1868 shafts were sunk at Wassel Grove and Manor Farm near the south end of the coalfield in search of the 'Thick coal,' it being assumed that all the coal-seams of the north end would be found to the south. Knowing the dip of the beds it was not difficult to calculate the depth at which each seam should be met with, and the several minor seams were found at the depths expected, but instead of coming down into the 'Thick coal' the boring instrument passed into a conglomerate of pebbles, formed of fragments of Silurian rocks intermingled with stems of Carboniferous plants, and resting upon Silurian rocks. It was unmistakably a portion of the beach formed by the Lower Carboniferous sea upon the slopes of the ancient Central Land[3].

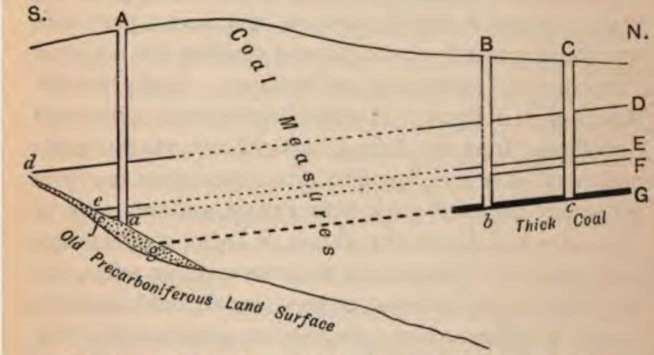

Fig. 50.—SECTION OF PORTION OF SOUTH STAFFORDSHIRE COALFIELD.
(After A. H. Green.)

A.B.C Borings; D.E.F.G Coal-seams. *fg* Conglomerate on old shore line.

From the neighbourhood of Coalbrook Dale the coast-line must have curved round towards the north-west into Wales, for around the hilly district of North Wales conglomerates of Lower Carboniferous age occur which indicate the course of the old shore line westwards between Anglesea and Carnarvonshire. The main part of Wales with its high lands of Silurian and Cambrian rocks undoubtedly formed part of this central land.

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[3] *Coal Commission Report* (1871), vol. i. p. 120.

Its boundaries on the south may be traced by similar reasoning, and it can be shown to have been a peninsula stretching across from east to west dividing the northern Carboniferous basin from the southern. Briefly the evidence is as follows. If the Carboniferous Limestone be followed from the Bristol coalfield towards the north and north-east it is found to thin rapidly, and the beds which are 2600 feet thick near Bristol, are only 1500 at Chepstow and 840 in the Forest of Dean, a diminution in thickness of 1760 feet in about twenty-five miles. If this attenuation continued at the same rate, the Limestone would have thinned away entirely ten miles north of the Forest of Dean. A similar thinning may be traced in the South Wales coalfield, the thickness of the Limestone on the southern border being from 1000 to 2000 feet, while on the northern border it is only 500 feet thick, and near Haverfordwest dies out altogether and is overlapped by the Coal-measures[1]. We shall not be far wrong therefore in assuming that the line of the southern coast of this peninsula extended from Pembrokeshire to the north of the Forest of Dean coalfield. From this point we have evidence that the coastline extended eastwards, passing Northampton a little to the north, away through the Eastern counties. At Gayton, 5 miles to the S.W. of that town, borings through the Mesozoic rocks reached Lower Carboniferous beds at a depth of 699 feet, consisting of impure limestones, sands, and shales of no great thickness, which were proved to be thinning towards the north by another boring at Orton twelve miles north-east of Northampton, where the Carboniferous were found to be entirely absent, the Mesozoic strata resting on rocks which appeared to belong to the same series as the volcanic group of Charnwood forest [5].

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[1] *The Building of the British Isles.* By A. J. JUKES-BROWNE. p. 72.

The evidence adduced proves that there stretched across Mid-England in Lower Carboniferous times, a peninsula of land in the way shown in the map (Frontispiece), which broadened out westwards so as to include the hilly and mountainous regions of Wales. Did this land, it may be asked, extend across the Irish Channel, or was it terminated by the Welsh coastline? Probably the former, for at Howth representatives of the Carboniferous Limestone occur affording by their conglomeratic character unmistakable evidence of the proximity of land. It seems likely therefore that the peninsula was continued across the Irish Channel, so as to include portions of Wicklow and Wexford. Further to the north, near Dundalk, there is evidence, furnished by conglomerates, that a large part of County Down must also have been land. This is indicated in the map as an island. It is interesting to note also that at the southern end of the Isle of Man Carboniferous Limestone occurs with littoral beds that seem to indicate that the northern part was above water in those times, and probably formed a small island in the Carboniferous sea.

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[5] *Quart. Journ. Geol. Soc.*, vol. xl. p. 482. Range of the Palæozoic Rocks beneath Northampton. By H. J. Eunson.

To the south of the British area there is reason to suppose that the greater part of Brittany formed part of a land area the boundary of which probably crossed the Channel. It seems likely that it included the extreme southern point of Cornwall, for the Carboniferous series of Devonshire are marked by an absence of any thick or pure limestones, and an abundance of sedimentary deposits indicating deposition not far from land, while the overlap of some of the upper beds on the lower in Cornwall makes it probable that the shores of this land could not be far off to the south or south-west.

Many years ago, in his notable paper 'On the possible extension of the Coal-measures beneath the south-eastern part of England,' Mr. Godwin Austin gave evidence for believing that Scandinavia and parts of northern Europe formed a great continental land-area in Carboniferous times[6]. The constitution of the Millstone Grit, as was pointed out on an earlier page, confirms that view. Whether the narrow peninsula crossing Mid-England was united on the east with this land or merely formed an island, it is impossible to say, but doubtless the northern land which included the Highlands of Scotland and stretched westwards and south-westwards to the borders of Ireland was continued eastwards to join Scandinavia and so form part of northern continental area.

How far the land extended to the north and west it is impossible to say, and no attempt has been made on the map (Frontispiece) to indicate its boundaries. It is not unlikely that an arm of the sea ran up into the land north of Ireland where the deep trough bounded by the 1000-fathom line lies.

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[6] *Quart. Journ. Geol. Soc.* vol. xii. p. 38.

These then were the salient features of the distribution of land and water in the area of the British Islands in Lower Carboniferous times. During the deposition of the Millstone Grit and Coal-measures the area was undergoing subsidence, so that by the close of upper Coal-measure times the land had become more restricted, although in the main its position remained the same, as is proved by the distribution of the beds. The Upper Carboniferous will be seen by the following table of thicknesses to thin away from the north towards Mid-England, indicating the continued existence of the central peninsula of land, while the thickening towards the north and west proves that the source of sediment still lay in that direction [7].

COMPARATIVE VERTICAL SECTIONS OF UPPER CARBONIFEROUS STRATA.

	Burnley District, North Lancashire, N.N.W.	Mottram District, East Cheshire.	North Stafford-shire.	Leicestershire and Warwickshire, S.S.E.
Coal-measures	8,460	7,630	6,000	3,000
Millstone Grit Series . . .	5,500	2,500	500	100 to 300
Total in feet	13,960	10,130	6,500	3,100 to 3,300

The deposition of this great thickness of sedimentary beds constituting the Coal-measures, all indicating shallow-water conditions, necessarily implies a continued subsidence of the sea-bed, and to some extent also, no doubt, of the land-areas, but that the land did not participate in the depression to the same extent as the sea-bed is proved by various interesting circumstances. In the South Staffordshire coalfield to the north of the central peninsula the coal-seams show a tendency to split up as they are traced from south towards north. (Fig. 51). The well-known seam of 'Thick coal,' which is about 30 feet thick south of Bilston, is found when traced northwards to split up into several seams, so that at Essington, five miles distant, it consists of ten seams separated by an aggregate thickness of 420 feet of sandstone. What does this splitting up mean? There can be no doubt that the coal-seams were originally formed on an approximately horizontal surface. It is evident therefore that there must have been a subsidence increasing progressively in amount from south to north in the area of the Staffordshire coalfield, so that a more rapid subsidence at Essington than at Bilston led to an influx of sea-water, in which a bed of sandstone was laid down which was overlaid again by another seam of coal.

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[7] *Coalfields of Great Britain.* By EDWARD HULL, M.A., F.R.S., 4th edition, p. 517.

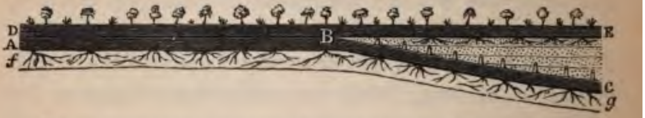

Fig. 51.—DIAGRAM SHOWING SPLITTING OF COAL SEAMS.

E and C two seams of coal uniting at B to form one seam A D.
f. g. underclay with Stigmaria.

Similarly another depression led to the deposition of a second bed of sandstone, and so on. All the while the deposition of vegetable matter at Bilston continued uninterruptedly, so that the ten seams at Essington traced towards Bilston run into one another and form a single seam.

A similar splitting of seams when traced away from the central land has been observed in the Warwickshire and other coalfields, and it furnishes conclusive evidence that the sea floor sank during the deposition of the Coal-measures more rapidly than the adjoining land-areas. This we may fairly attribute to the pressure of the accumulated sediments; and the compression of rocky material at depths below the surface caused in this way was no doubt finding relief in the vigorous volcanic action that manifested itself during Carboniferous times all along the borders of the land-area in the midland valley of Scotland.

As the result of the steady submergence and deposition of material in Upper Carboniferous times, the whole of Great Britain and Ireland, with the exception of the neck of land across Mid-England, the North of Scotland, and insignificant portions of Ireland and of the extreme South of England, were covered with Coal-measures. When we come, however, to examine the present distribution of coalfields in the British area (Geological map, Plate VIII), we are struck with the exceedingly meagre remnants which now occur at the surface. It is important however to consider to what extent coal-bearing beds may be concealed beneath newer formations. Around the margins of many of the existing coalfields the Coal-measures are found to pass underneath newer beds of Mesozoic age, where they are frequently reached at workable depths by borings, but even allowing for this there is no very great extent of coal preserved.

That coal-beds extend beneath the newer strata of south and south-east England has long been suspected. In 1856 Mr. Godwin Austin, in the paper already referred to, 'On the possible extension of the Coal-measures beneath the south-eastern parts of England,' expressed the opinion, based on a study and comparison of the structure of the coalfields of the continent of Europe and of Great Britain, 'that we have strong *a priori* reasons for supposing that the course of a band of Coal-measures coincides with, and must some day be reached, along the line of the valley of the Thames, whilst some of the deeper-seated coal, as well as certain overlying and limited basins, may occur along and beneath some of the longitudinal folds of the Wealden denudation[8].' He pointed out that in an artesian boring at Calais true Coal-measures were met with at a depth of 1100 feet, which seemed to predicate a continuation between the coalfields of southern England and those of the Franco-Belgian area. Buckland and Conybeare, in 1822, pointed out the similarity between the Bristol and Belgian Coalfields, and De la Beche suggested that the Somerset Coal extended under the newer formations to the east.

In a Report prepared for the Coal Commission, Professor Prestwich gave reasons for believing that the beds of the South Wales and Somersetshire coalfields, which evidently were originally continuous, would be found still further to the east, beneath the newer rocks; and he concluded that as 'the Palæozoic strata were reached at Harwich at a depth of 1026 feet, and at London at a depth of 1113 feet, it is probable that in the south-east of England the depth of the old surface of Palæozoic rocks will not exceed 1000 or 1200 feet'[9].

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[8] *Quart. Journ. Geol. Soc.* vol. xii. p. 373.

In the Weald boring Jurassic rocks were proved at a depth of 2000 feet, but two years ago borings at Shakespeare Cliff near Dover penetrated true Coal-measures containing thin coal-seams at a depth of 1120 feet, thus confirming the accuracy of the inferences drawn on theoretical grounds by Mr. Godwin Austin and Professor Prestwich so long ago.

In northern England and in Ireland, however, there is no general concealment of Carboniferous beds under newer strata as is the case in the south. In many parts of those regions there is conclusive evidence that the upper beds have been removed by denudation. The present arrangement of the Carboniferous strata proves that the period was brought to a close by great earth movements which threw the beds into anticlinal and synclinal curves, having an east and west direction. These are shown to perfection in the Pendle chain of hills (Fig. 26), in the South Wales coalfield, in the Somersetshire coalfield, and in other parts. We have evidence that somewhat later, movements in a north and south direction took place, of which the most marked example is furnished by the Pennine range. This consists of an anticlinal of Carboniferous rocks, from which the Coal-measures, undoubtedly once continuous between the Lancashire and Yorkshire coalfields, have been removed by destructive agencies. The denudation of the upper portions of the anticlinal curves resulting from these two sets of movements—E. and W. and N. and S. —has left the Coal-measures in synclinal basins, an arrangement so characteristic of many of the coalfields.

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[9] *Coal Commission Report* (1871), vol i. p. 153.

This upheaval at the close of the Carboniferous period was followed after a long interval by another subsidence of the area, and over it the Mesozoic sea spread burying the greater part of the remnants of the Carboniferous beds under newer strata of Poikilitic age. It is to this fortunate circumstance that we owe the preservation of much of the rich coal deposits of central England from destruction by denuding agencies. Whence was the sedimentary material derived that formed these newer beds? A study of their comparative thicknesses shows that they attenuate rapidly towards the south-east. This points to the conclusion that the old Carboniferous land that lay to the north and west still existed, and there is reason for believing that it had been augmented by the elevation and addition to it of the greater part of Ireland. It is a significant fact that almost the whole of the Irish Coal-measures have been removed by denudation, only two or three small patches being left forming the unimportant coalfields of the south and the more valuable deposits of Leitrim, Tyrone, and Antrim in the north. The coal-beds of Ireland were not covered, as in England, by a protecting mantle of Poikilitic and later strata. Thus Ireland was less fortunate than England in that, owing to the upheaval that took place at the close of the Carboniferous period, she formed part of a great land area to the west and north which was undergoing extensive denudation, so that her Coal-measures were almost entirely removed by destructive agencies. The material resulting from this destruction was swept into the Mesozoic sea, and was laid down over the submerged area of central and southern England, covering up and preserving from destruction much of those rich coalfields in which are stored the mineral wealth which has given to England her pre-eminence in the commerce and industry of the world. By the removal of the upper (coal-bearing) beds the lower (limestone) became the surface-rock of large tracts of country—a surface-rock which furnishes a soil singularly inhospitable and unfavourable to successful agricultural operations. Assuredly it was not without reason that an Irish geologist with a touch of Celtic poetry, once said, 'At this time Ireland stripped herself to clothe her sister, and the debt ought never to be forgotten.'

REFERENCES TO THE MORE IMPORTANT ATTEMPTS TO RESTORE THE PHYSICAL GEOGRAPHY OF CARBONIFEROUS TIMES.

Manchester Science Lectures. Second Series, p. 134. (Coal, by A. H. GREEN, M.A., F.R.S.) John Heywood, Manchester, 1871.

Coal, its History and its Uses. (Chapters i and ii. The Geology of Coal, by A. H. GREEN, M.A., F.R.S.) Macmillan & Co., 1878.

Contributions to the Physical History of the British Isles. By E. HULL, LL.D., F.R.S., pp. 79–86. Edward Stanford, 1882.

A Chapter in the Physical Geography of the Past. By HORACE T. BROWN, F.G.S. Presidential Address. Trans. Burton-on-Trent Nat. Hist. and Arch. Soc. Vol. i. p. 37. 1887.

The Building of the British Isles. By A. J. JUKES-BROWNE, B.A., F.G.S. Chapter vi. George Bell & Sons, 1888.

CHAPTER XVIII.

CONCLUSION.

WE have now sketched the method by which these restorations may be worked out. Our study of the structure of the British Isles will have made clear in its broader features the nature of the evolution by which the land-areas have come to assume their present forms. There is every reason to believe that the positions of the great continental and oceanic areas were blocked out by large crust movements in remote times. The deep sea soundings of recent years have shown that the average depth of the great oceans is very great, a fact which points to the high antiquity of the deeper parts of the oceanic basins. How far the interchange between land and water has gone on throughout geological time is still a matter of controversy. The present position of our knowledge was well stated by Professor J. Geikie in his Presidential Address to the Geographical Section of the British Association at Edinburgh (1892)[1]: 'Our lands, he said, 'are distributed over the surface of a great continental plateau of irregular form, the bounding slopes of which plunge down more or less steeply into a vast oceanic depression. So far as geological research has gone, there is reason to believe that these elevated and depressed areas are of primeval antiquity—that they antedate the very oldest of the sedimentary formations. There is abundant evidence, however, to show that the relatively elevated or continental area has been again and again irregularly submerged under tolerably deep and wide seas. But all historical geology assures us that the continental plateau and the oceanic hollows have never changed places, although from time to time portions of the latter have been ridged up and added to the margins of the former, while ever and anon marginal portions of the plateau have sunk down to very considerable depths. We may thus speak of the great world-ridges as regions of dominant elevation, and of the profound oceanic troughs as areas of more or less persistent depression. During the evolution of our continent, crustal movements have again and again disturbed the relative level of land and sea, but since the general result has been to increase the land surface and to contract the area occupied by the sea, it is convenient to speak of the former as the region of dominant elevation, and of the latter as that of prevalent depression. Properly speaking, both are sinking regions, the rate of subsidence within the oceanic trough being in excess of that experienced over the continental plateau.'

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[1] *Scottish Geograph. Mag.* Sept. 1892.

The evidence seems to indicate that the regions subject to oscillations of level bringing about alternations of land and water conditions, have not extended very far out from the coast-lines of the continental areas. There appears to have been, as a rule, a constant interchange of small portions of oceans and continents around the continental coast-lines so that in the course of ages the distribution of land and water has undergone extensive rearrangement by the accumulation of small changes continued throughout long periods. On the other hand, it seems equally certain that there have been periods in the Earth's history when large physical changes, indicated by the great 'stratigraphical breaks,' were accomplished more rapidly by a few important steps.

The older Palæozoic deposits exhibit so much uniformity of lithological character over wide areas and in different parts that we may fairly assume great similarity in the physical conditions all over the world during their deposition. The evidence seems to show that the continental land lay chiefly in high latitudes, while to the south groups of islands broke the monotony of wide stretches of ocean. 'In Palæozoic times,' says Professor J. Geikie, 'relatively small areas of the continental plateau appeared above the level of the sea. Insular conditions everywhere prevailed. But as ages rolled on, wider and wider tracts of the plateau were exposed, and this notwithstanding many oscillations of level. So that one may say there has been upon the whole a general advance from insular to continental conditions; in other words, the sea has continued to retreat from the surface of the continental plateau.'

It seems clear that in these early times, 'when insular conditions prevailed and the major portion of the primeval continental plateau was covered by shallow seas, mechanical sediment would be swept by tidal and other currents over enormous areas, and that these sediments would assume a more or less uniform character.' As time rolled on, this uniformity became less marked, and the later Palæozoic deposits exhibit greater diversity of character. We have seen that in Carboniferous times a great land-area lay to the north, while a neck of land stretched across mid-England, the greater part of England and Ireland being submerged. During the Mesozoic period frequent oscillations of level occurred in the area of the British Isles, but the chief part of central and southern England remained submerged throughout the period, while the Highlands of Scotland continued to form part of a land-area. In later Mesozoic times the extent of subsidence increased and led to the deeper water conditions which prevailed during the deposition of the Chalk. The evidence indicates that the land-areas at that time were much interrupted so as to admit of free circulation of warm currents from tropical to colder regions, giving rise in our area to the warm climate to which the fossil forms entombed in the Mesozoic rocks bear witness. Thus the deposits of the Mesozoic period exhibit greater diversity of character than those of the Palæozoic, while in the Tertiary period this diversity is still more marked. The deposits of Tertiary age in the area of the British Isles are local and very specialized, indicating continental conditions over the greater part of the area.

We may now sum up the process of evolution of the area of the British Isles succinctly as follows:—In early Palæozoic times what is now the mountainous region of the west and north, including Wales and parts of Ireland and Scotland, already existed as a land area. It has since undergone constant denudation by which its vertical elevation has been reduced, and the materials resulting from the destruction have been deposited in the seas washing its shores so as to form new strata. The destructive agents, air, frost, rain, rivers and glaciers, have unceasingly 'drawn down the hills' and sown 'the dust of continents to be.' Gentle oscillations of level have time after time brought the new rocks thus formed to the light of day, and the land has grown horizontally by accretions to its coasts. Thus age after age by these natural operations there has resulted a greater and greater specialization in the physical features of the land, and on the whole an increase in extent.

In the sketch of the earth's history given in this volume we have been dealing with only a part of the whole period of the existence of our globe, viz. the period since the beginning of the deposition of the stratified rocks. We have (using again the illustration of an organism) been treating of the physiology of the earth and the processes of waste and renewal, within the period corresponding to that from birth to maturity of a living creature. A treatment of the complete history would require that the pre-natal and post-obital states should also be dealt with. For light upon those states of the earth we must turn from Geology proper to Astronomy and Physics. 'We have now got,' said Dr. Hutton in his *Theory of the Earth*, 'to the end of our reasoning; we have no data further to conclude immediately from that which actually is. But we have got enough; we have the satisfaction to find, that in nature there is wisdom, system and consistency. For having, in the natural history of this earth seen a succession of worlds, we may from this conclude that there is a system in nature; in like manner as, from seeing revolutions of the planets, it is concluded that there is a system by which they are intended to continue those revolutions. But if the succession of worlds is established in the system of nature, it is vain to look for anything higher in the origin of the earth. The result, therefore, of this physical enquiry is, that we find no vestige of a beginning,—no prospect of an end.'

The science of Physics has made gigantic strides since Hutton's time, and the spectroscope has carried back the history of the earth until it is lost in a nebula. Truly we find no vestige of a beginning; but recent advances have warned us to exercise great care in attempting to place a limit to the possible backward extension of the earth's history. As to the future, the doctrine of the 'Dissipation of Energy' clearly points to an end, at any rate of the present order of things.

'The whole store of energy now in the sun,' says Lord Kelvin, 'whether of actual heat, corresponding to the sun's high temperature, or of potential energy (as of the not run-down weight of the clockwork)—potential energy of gravitation depending on the extent of future shrinkage which the sun is destined to experience, is essentially finite; and there is much less of it now than there was 300,000 years ago. Similar considerations of action on a vastly smaller scale are, of course, applicable to terrestrial plutonic energy, and thoroughly dispose of the terrestrial "perpetual motion" by which Lyell and other followers of Hutton, on as sound principles as those of the humblest mechanical perpetual-motionist, tried to find that the earth can go on for ever as it is, illuminated by the sun from infinity of time past to infinity of time future, always a habitation for race after race of plants and animals, built on the ruins of the habitations of preceding races of plants and animals. The doctrine of the "Dissipation of Energy" forces upon us the conclusion that within a finite period of time past the earth must have been, and within a finite period of time to come must again be, unfit for the habitation of man as at present constituted, unless operations have been, and are to be, performed which are impossible under the laws governing the known operations going on at present in the material world [2].'

We may perhaps venture in conclusion to conjecture that in some of the other heavenly bodies of our system we have examples of what our earth may eventually become. The planet Mars is smaller than the Earth, and has progressed through its physical evolution at a rate more rapid than would be possible with a larger globe like ours. The shaded portions of the surface of Mars, which are taken to be oceans, present the appearance of long narrow strips, extending in length over 3000 miles. If the Atlantic Ocean could be drained away 2000 fathoms, so as to leave only the deeper troughs, it would present much the appearance of the oceans of Mars. The phenomena of the stratified rocks indicate that in former

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[2] *Fortnightly Review*, 'The Dissipation of Energy.' By Lord Kelvin. March 1892, p. 321.

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